

A METHOD OF SCHEDULE AND ROUTE PLANNING IN URBAN MASS TRANSIT

by

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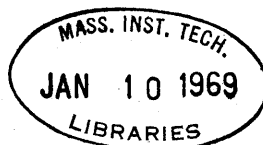
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ABSTRACT

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Submitted to the Department of City and Regional Planning on September 25, 1968, in partial fulfillment of the requirement for the degree of Doctor of Philosophy in City and Regional Planning

Continued arbitrary reductions in service are not a panacea for the financially stricken urban public transportation industry. In seeking to reduce costs, "it is not always realized by management that a cut in mileage during a period of fall-off in revenue will result in a reduction in patronage much beyond the normal or average fall-off." (Robert T. Pollock, former head of the Department of Schedules, Cleveland Transit System, chapter 2 footnote 35).

More attention must be paid to making urban mass transit service more attractive in such a way that the cost of doing so will be equal to or less than the additional revenue encouraged. To do this, new methods of data collection and analysis, and new approaches to service decisions, based on a better understanding of the costs of such decisions and of why the urban traveler chooses to make (or not make) his trips as he does, must be developed.

This thesis develops such new methods and approaches. The proposed method of Schedule and Route Planning is:

1. Market oriented, focusing on the sensitivity of demand as well as cost to changes in service, and on the potentially profitable demand for new or improved transit service. Relationships are found to exist between level of service and transit usage (chapter 5). These relationships can be measured, and applied to decisions on level of service in a manner that will enable the determination of an "optimum," or at least better, level of service for the desired objectives (maximum profit, maximum number of passengers, etc.).
2. Based on incremental analysis, making use of marginal cost analysis (chapter 6). The marginal (added) cost of a service increment is found to vary from route to route and change to change, depending on a number of factors; it is always less than the average accounted cost.
3. Systematic (as defined in chapter 3), drawing on the discipline of Systems Analysis to make what is now an essentially disorganized, inconsistent art (chapter 2) into a systematic, consistent science capable of being programmed for the computer.

It is hoped that the new approaches and findings in this thesis will inspire further efforts along similar lines in and out of the transit industry. In particular, the effect of service changes on demand; the adaptation of the model to the computer; and the improvement of data collection procedures in the industry are suggested as fruitful areas for research.

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Acknowledgment

The author is especially indebted to the people in the New York City Transit Authority and the Massachusetts Bay Transportation Authority without whose cooperation and generosity this thesis could not have been completed. In particular, in New York, William Lassow, Leo J. Cusick (now of Boston), Joseph Kilkenney, K. Pollack and William Tiedemann; and in Boston, J. Willard Burditt, Charles A. Waelde and Arthur Jaehnig, have all been most helpful in providing me with the necessary information, and in commenting on my research. Space does not permit the listing of the many other employees of these agencies that have in one way or another been of help, although a special thanks goes to the men in the Rapid Transit Schedules Department in New York for their many constructive and enlightening comments, discussions and interest in my work for many years.

The author is grateful to his Thesis Supervisors, Prof. John T. Howard of the Department of City and Regional Planning and Asst. Prof. Richard L. deNeufville of the Department of Civil Engineering, for their patience and many constructive comments throughout the development of the thesis. Thanks is also due for advice, encouragement and influence over the years to Profs. Marvin Manheim, Aaron Fleisher and Mr. Thomas Harvey of the Massachusetts Institute of Technology and Profs. John Meyer, Martin Wohl and Lewis Schneider of Harvard University; as well as for grants from the United States Department of Transportation and General Motors.

Through many hours of discussion, previous work in the area, and long professional association, Jason Fane has contributed greatly to this work. The task of typing the thesis was borne principally by Mrs. S. Josephs and Mrs. S.A. Krauss. Thanks are also due to the author's parents and to Triss for their patience, understanding and forbearance during the preparation of the manuscript.

The author wishes to pay special tribute to Leo J. Cusick, William Lassow and Joseph Kilkenny, whose early and continuous interest and encouragement were a principal source of motivation in the author's decision to pursue his studies and career in the direction manifest in this thesis.

To the Riding Public

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CHAPTER I
INTRODUCTION

CHAPTER I

Introduction

In the past, changes in schedules and routes on many United States urban transit systems have been conservative, random and piecemeal. Typically, decisions as to whether or not there are enough riders to "justify" existing or new service are made on the basis of peak load point surveys and average cost techniques. Information on distribution, origins and destinations of passengers; responses over time to changing service; as well as information on marginal variations in operating costs are not used as input to these decisions. What data is used and gathered from year to year is seldom compared for the purpose of finding out what effect changes have had on revenues and costs. Past experience is rarely used as a guide to future decisions.

Two interrelated deficiencies are involved. One is in the scheduling process itself. Because it has been production oriented (as opposed to market oriented, hence concerned primarily with costs) it has focused on the costs of the service provided, and even then only on an average cost per vehicle mile. This has restricted the range of alternative solutions evaluated for a given problem, and indeed the identification of problem areas themselves. Emphasis has been on one problem: cost of service (often equivalent to deficit from operations). The scheduling process has been primarily one of controlling costs within boundaries acceptable to management and the communities which

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must pay them, subject to certain arbitrary and inconsistently applied standards of passenger comfort, frequency of service, etc. The second deficiency is that at the same time, because demand was thought to be too inelastic with respect to service to affect the economics of operating decisions, estimated changes in revenue with respect to service were not calculated. To the author's knowledge, no urban transit system in this country has yet applied a formalized method of evaluating the optimum levels of service for various passenger markets based on data on elasticity of demand. Yet there is indeed a "market" for transit service, in that transit is competing with other "product lines," principally the automobile, and choices are made by the urban traveler.

The urban tripmaker incurs monetary, temporal and psychological costs each time he takes a trip. These costs, actually the total price of the trip to the traveler, are the basis for his choosing how he travels, and whether he makes a trip at all. A small increase in the trip price of a given mode or route will result in a few less travelers using the service. Since each traveler has his own sets of values and priorities, the difference will represent those travelers who were incurring a trip price on the given service only slightly lower than on some other mode or route. The marginal increase in trip price was enough to drive these people out of the market for transit service entirely. The price via the given service being higher than the trip price via a competing mode or route,

these travelers switched to the mode or service with the lower total trip price (or, if no mode offered a sufficiently low trip price, they stopped making the trip).

Since World War II, the total trip price via mass transit in many areas of the United States has risen, while the total trip price via automobile (particularly for non-work trips) has fallen. This has been a function of several factors, including rising incomes (and hence rising value of time to the traveler), more dispersed origin-destination patterns, and the construction of interstate highways. It has also been abetted by the decline in transit service quality (frequency, speed, route coverage, etc.). Not surprisingly, this has gradually diverted passengers from transit to automobile for many trip purposes.

The nature of this travel market with which urban mass transit management is dealing, and the implications for policy making, are discussed by Lewis M. Schneider.¹ In an article on "A Marketing Strategy for Transit Management",² he notes that "The key variable may be the quality of transit management itself." This thesis offers a market-oriented approach to schedule and route planning which is designed to improve the quality of transit management (that is, of the decision-making process).

The thesis offers a systematic approach to determining the impact on costs and probable benefits to passengers and operator of alternative marginal investments by the operator (community) in schedule and route planning changes. "Systematic" means, in this context:

1. Breaking down the process of scheduling into the

smallest units of the planner-analyst's decision.

2. Making these units of decision explicit.
3. Codifying these units of decision in a manner conducive to computer manipulation.
4. Specifying the data necessary for these decision units.
5. Quantifying, as much as possible, the measures used as input into the units of decision.

"Marginal" investments are changes affecting only the short-run variable costs of a transit system. They are changes in schedules and routes made within a fixed physical plant (the purchase of new buses falls into a shadow area, and could be considered as semi-variable).

The costs and benefits of such changes to the operator are the changes in cost of operation (computed on a marginal cost basis, not an average cost basis), and the changes in revenue. The costs and benefits to the community are the increases or decreases in total trip prices (monetary and non-monetary) - i.e. in mobility - resulting from the various changes, or the change in peak hour or peak corridor automobile trips.

The resources available to the author do not allow the precise determination of the elasticity of demand. A framework for systematic schedule and route planning can be provided without defining such data. It is important, however, that examples be developed of the kind of work that should be done on this subject by people with enough resources. The omission of any consideration of demand can lead and has led to schedule and route changes whose ap-

parent cost reductions are obliterated by even larger revenue reductions, as will be documented in the course of this thesis.

Therefore, the proposed method will evaluate some hypotheses about changes in demand, as examples of work that can be done to estimate demand elasticity, using statistical tools appropriate to the data. At some future date the probability of these hypotheses may be determined, but this will not be a part of this thesis. The hypotheses, although statistically valid as estimates of future response of demand to changes in service, will not be assumed to have provable predictive validity. They will not, however, be meaningless: they are the best available measures to date, and can be used in actual practice with success, as their use in demonstrating the method will show.

The urban traveler is today highly demanding of precision in the product (public urban transit) design, both in time and location, due to the competitive flexibility of private and pedestrian means of transportation. Hence costs (prices) and benefits to both traveler and travel agent are more sensitive to relatively small changes in schedules and routes. At the same time, public transit management has continuous control over a wide range of alternative changes in schedules and routes. Such incremental changes form the bulk of the decisions affecting modal split (outside of plans for expansion of rapid transit lines) made by a transit system. For these reasons the method developed in this thesis addresses itself to the analysis of marginal changes in transit schedules and routes, rather than to such ques-

tions as the location of fixed investments such as rapid transit lines and stations. However, many elements of the method are applicable to the latter sort of analysis.

The method of schedule and route planning developed in this thesis provides a more exact and more inclusive tool for decision making in urban mass transit than is currently available. It is a tool which the author hopes will be easily understood and applied; which introduces modern planning and systems engineering methods into an area of urban planning and management sorely in need of such methods; and which the author feels can lead to the viable provision of better transit service, thus improving the quality of urban life by improving what the author sees as a present imbalance in the relative use of private and public transportation in our larger cities.

The thesis will begin by describing, in chapter two, the scheduling process of three major transit systems: New York, Boston, and Cleveland. Present procedures are discussed and omissions highlighted. Published efforts at systematic or optional scheduling methods are then briefly discussed and their relevance to the thesis indicated.

Having identified the lack of systematic organization in the present methods of schedule and route analysis in chapter two, chapter three defines "Systems Analysis" and its application to Schedule and Route Planning. Proceeding from this groundwork, chapter four presents a model of mass transit scheduling and route planning. The model is in two parts: the first defining the elements of transit service (schedules and routes) in measurable terms, their relationship to each

other, and to the environment; the second outlines the proposed method of generating and evaluating alternatives.

The second, or decision-making, part of the model is described and illustrated in more detail in chapter seven. In order to do this, it is first necessary to develop hypotheses and present data on the effects of changes in schedules and routes on revenues (chapter five) and cost (chapter six). Chapter five also reviews previous modal split research and mass transit demonstrations, presents a theory of modal choice, and discusses the variability and uncertainty of the data used in the hypotheses or otherwise available. Chapter six develops variable cost functions for New York in detail, and briefly looks at costs in Boston.

After applying this data to the applications of the model illustrated in chapter seven, a cohesive view of the model in practice is given in chapter eight. Each step in the proposed method of Schedule and Route Planning is illustrated using the B-3 bus route in Brooklyn as an example. Alternatives are proposed and evaluated using the data developed in chapters five and six.

Footnotes

1. Marketing Urban Mass Transit (Boston, 1965).
2. In Traffic Quarterly (April, 1968), 283-294.

CHAPTER II
SCHEDULE PLANNING IN THREE CITIES

CHAPTER II

Schedule Planning in Three Cities

In this chapter, the scheduling process of three major transit systems is described. Omissions from a systems analysis point of view are described (see chapter 3 for a discussion of systems analysis). Published efforts at systematic or optimal scheduling methods are then discussed, and their relevance to the thesis indicated.

Table 1 gives a summary comparison of the scheduling process in the three cities.

A schedule specifies the route(s), times at which vehicles arrive and leave specified points along the route(s), times at which vehicles arrive and leave terminals, the number of cars in a train in a rapid transit schedule; the routes and departure times to and from specified points of storage, the assignment of operators to these various trips, and their places and times of report and completion, fringe benefits, payments, etc.

The number of persons using a transit service varies from hour to hour, day to day, week to week. The most obvious example of this variation is the great peaking of riding in the rush hour periods (see fig.2 and exhibit 1, Appendix I). There are many other factors however which cause riding to fluctuate: changes in store closing times, factory shift times; sports events, school schedules. Numerous factors can affect riding on individual lines - for example, visiting hours at a hospital or local school events. The extent of variation of system aggregate usage alone is

evident in figure 1.

The primary purpose of the schedule for most transit systems then, is to serve these varying demands, according to a set of objectives or constraints on acceptable load factors, service frequencies, etc. at minimum cost to the company or municipality. Two basic controls over costs are used: the amount of service provided, and the way in which trips are allocated to operators (subject to the work rules set forth in the contract(s)).

Throughout this chapter, three major urban transit systems will be used to illustrate the present method of schedulmaking in the industry. These cities were chosen, the first two because the author has done most of his research in their methods (New York and Boston); the third (Cleveland) because of its reputation as having, along with Toronto, the "best" schedulmaking procedures in North America.

New York and Boston are in many ways considered, among professionals in the industry, to be typical of the other old and large systems in the country; however, the author did not have at his disposal the kind of detailed information for such places as Chicago, Philadelphia, Pittsburgh, Los Angeles, San Francisco, St. Louis, and so on; thus the similarity cannot be documented here.

In certain respects Boston is not considered typical of the other cities, however; it is considered sub-standard. Boston has the reputation throughout the world transit industry of having least efficient utilization, maintenance and scheduling procedures and the worst maintenance procedures. In addition to the data presented in footnote 13, it

FIG. 1 MTA SYSTEM REVENUE BY DAY, MON. TOTAL, 1940

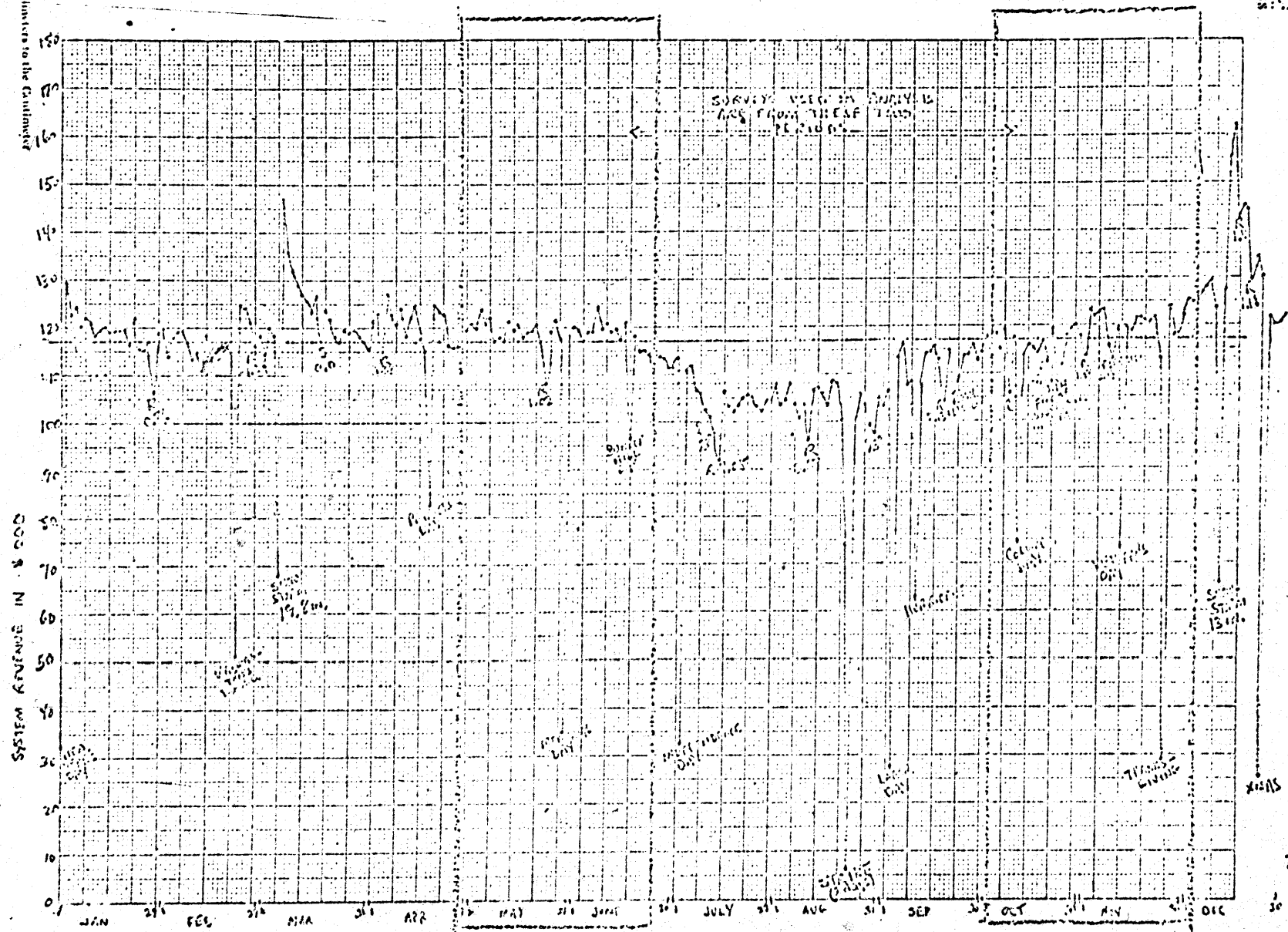
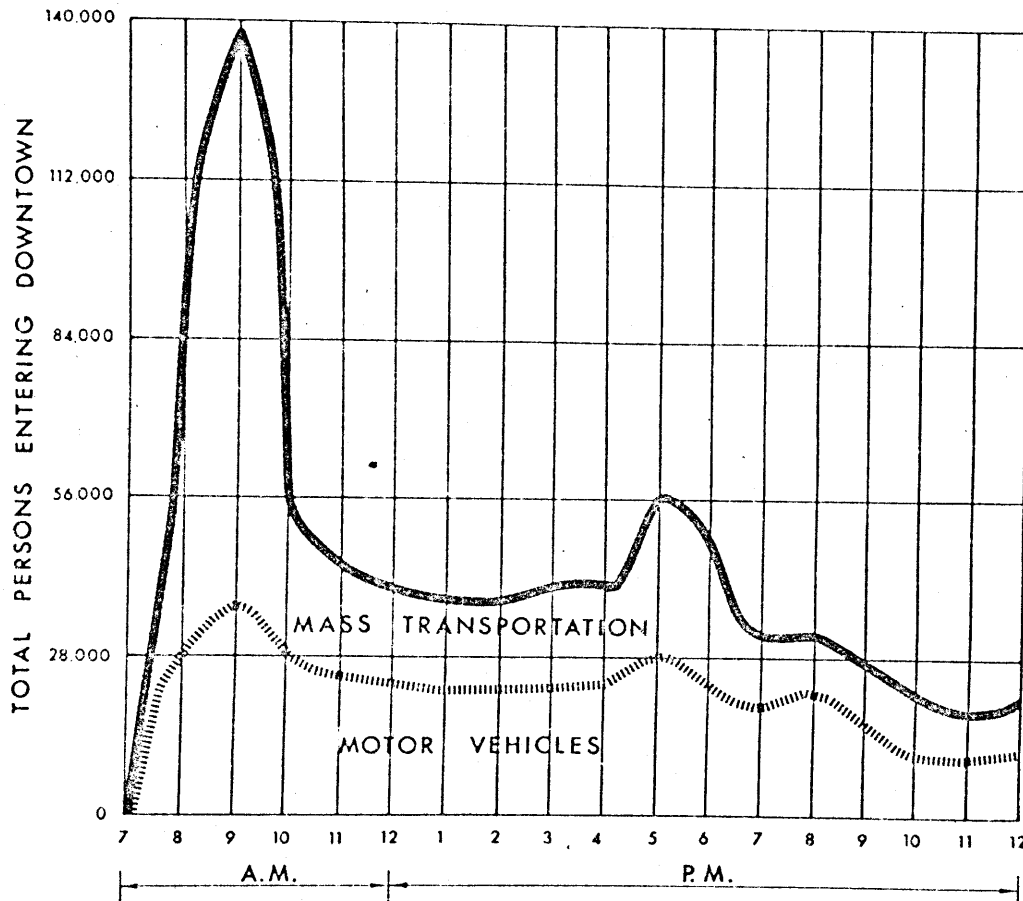


FIGURE 2

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HOURLY DISTRIBUTION OF PERSONS ENTERING DOWNTOWN BOSTON, 1958

SOURCE: B. C. SEMINAR RESEARCH BUREAU
STUDIES OF URBAN TRANSPORTATION, 1958

is worth noting in this regard that the cost per mile in Boston is the highest in the nation (in 1963, it was \$1.98 for rapid transit - next highest being \$0.86 in Chicago, lowest being \$0.484 in Cleveland; in Boston \$1.22 for bus, compared to \$1.07 in New York, about \$0.70 in cities the size of Boston).

The Traffic Check or Survey

The most common, and often the only, source of data which determines the service to be provided is the traffic check. This is a count of the number of people on board vehicles passing or stopping at a given point. It is taken by a man standing in the street whose experience in estimating vehicle loads keeps the error of such estimates, according to the transit industry, within 5% + or -. The checker either spends all his time doing this, or part of his time in the schedule department offices. As an aid to accurate estimation he knows the seating capacity of the various types of vehicles; the total capacity; the number of people that can cluster near a door; etc. He knows that when there are still a few seats left, some people will stand; he can count groups of 5, or 7, or 10 people; and so on. It is not difficult to do with some practice.

.Most transit systems consider headcounts by operators (drivers or conductors) to be less reliable, because of inexperience, a tendency to over-estimate small loads and the difficulty of estimating crowds (a conductor, of course, has no time to walk through a crowded train between stops).

Most operators don't want to make such counts, and demand extra time for them. Thus a separate checking force is used. The checkers are often unionized, sometimes not.

The checker records each vehicle's number, the time it passes, and the number of people on board. When more than one line passes a given point, the checker notes the destinations or records in separate columns. This will sometimes lead to confusion, particularly when separate lines are bound for the same destination; the checker may list^a vehicle under the wrong line.¹ Cleveland, in order to reduce such error and to better identify schedule adherence also has their checkers record the block numbers which operators place in their windows. All systems will use more than one checker if more than a few lines pass a given point. A typical Boston survey is shown in Appendix I, Exhibit 2.

Checks are usually taken at the point on each line where maximum loading occurs, as this determines the maximum needed service. The maximum load point, or peak point, is a location determined either through an on-off count (described below) or subjectively. Once determined, rarely changed, it is used as the peak point throughout the day. Other points on the line are not checked in Boston, and only irregularly checked in New York, regardless of its length. Lines with several peaks may be checked at more than one point. In general, the location and time of traffic checks is not very flexible. Cleveland is an exception to this generalization.²

Checks are most frequently taken during rush hours,

as the maximum vehicle and manpower commitment is at these times, but will often extend from about 6:30 A.M. to 10 or 11:00 P.M. The timing and frequency of checks varies widely from system to system. Boston takes 16 hour checks regularly one or more times each season for nearly all its lines. New York focuses on frequent rush hour checks, and regularly takes a 24 hour "cordon count" on all its major subway lines, while taking 95% of its bus checks from 6:00 A.M. to 10:00 P.M. Both Boston and New York pay very little attention to weekend traffic, or to the differences between evenings when stores are open or closed. Cleveland has a less ordered but more diverse coverage, concentrating on trouble spots or special situations (as opposed to Boston and New York, Cleveland has separate schedules for late store opening nights) and depending more on other types of checks and reports than do most other systems. On most systems, checks will be taken at special times or locations in contemplation of major changes in service.

The information obtained in these surveys is usually tabulated and summarized by 15, 20 or 30 minute periods by the schedule department, listing for each period the number of seats, the number of passengers, and number of vehicles. Schedules are normally built on the summary information. In Cleveland, such summaries have been abandoned as a waste of time and resources; schedules are built on individual vehicle observations, which results in less regular scheduled rush hour headways on some lines, but in more evenly distributed loads.

The ratio of checkers to revenue passengers varies

widely. Cleveland has 18, or one per 6,000,000 annual passengers; while New York has 12, or one per 36,000,000 annual passengers.

Other Types of Passenger Counts

New York and Boston do not use other data on passenger movements, although such data does exist in one form or another, and is sometimes collected by the transit agency itself. As an example of other kinds of data that a progressive transit management will use, consider Cleveland.C.T.S. uses three other kinds of data: 1) On-off counts, 2) Postcard surveys, and 3) Population data.

On-off counts are accomplished by putting a checker on a bus and having him count the number of people boarding and alighting at each stop. The purpose of this is several-fold: it establishes the location of one or more maximum load (peak) points, provides information on the turnover of riders along the length of a route (thus showing what the number of passengers surveyed at the peak point is as a percentage of the total boarding passengers), reveals especially heavy load points or transfer points, reveals dissimilar route sections, and so on. These counts are usually made on all buses in operation on a route in non-rush hours, or, in the rush hours on several. In 1967, for example, Cleveland stationed checkers on all its Owl trips (1:00 A.M. to 5:00 A.M.), one line at a time, to find out exactly how many riders they were getting and at what locations. (In contrast, halving of owl service on New York bus lines is based only on the subjective reports of a supervisor).

Postcard surveys are made by handing out cards to all

passengers boarding the vehicles, and riders are requested to fill in information concerning origin, destination, mode and route to and from the bus or train, etc. The cards are either handed back to the checker, or, more commonly, mailed in. Boston amassed such information back in 1963 under the aegis of Wilbur Smith & Co. for the Boston Regional Planning Project. The data contains a great deal of coding error, although it does prove fruitful through hand analysis.³ It has, however, not been used by the MBTA.⁴ New York just recently conducted such a survey on new routes established in November 1967 with the opening of the Chrystie Street Connection, but it is not normal practice there either. (see Appendix I, Exhibits 3 and 4).

Population data would include Census reports, data on new construction, Aerial Maps, etc. Subjective perusal of this material is employed extensively in considering new routes in Cleveland. No models for projecting the number of new riders on the basis of this data are used, however. St. Louis developed some empirical rules for estimating riding on new routes based on various population factors in connection with the Federal Demonstration Experiments there.⁵ In general, when this material is used in the industry, it is used subjectively, as in Cleveland.

Cleveland stopped making occasional tabulations of 24 hour revenue by line about $2\frac{1}{2}$ years ago, because the proliferation of multiple fares, transfers and passes made the accuracy of the counts dubious and the effort excessive. Further, the scheduling of one bus on more than one route often mixed reported revenues from several routes, making

allocation to one route an arbitrary procedure. Boston tabulates line-by-line daily revenue figures which, although not confused by transfer and pass arrangements, do have the same problem of extracting revenue collected from several lines and assigning it to one line (see Appendix I, Exhibit 5). New York publishes yearly revenue figures, thoroughly audited, by line (see Appendix I, Exhibits 6 and 7).⁶ Little use is made of any of this revenue data, however.⁷

The most accurate form of revenue counts, readings from the farebox and the counting of transfers collected at the end of each half-trip (i.e., one-way trip), has been employed in rare cases in scattered cities; in Boston, the most recent case was in March of 1966, when for purposes of deficit assessment it was necessary to know the number of passengers boarding in each city or town, and a fare-box reading and transfer count was made on those lines operating into two or more towns each time the bus crossed the border. Such counts, however, are often resisted by the unionized drivers without additional time and pay allowances, and are therefore not employed on a regular basis.

Turnstile counts are made in all cities with rapid transit lines; these are made daily for auditing purposes, with each change in shift. Hourly readings of the turnstiles at each station are generally made - usually by the station booth clerk (collecting agent) - for a 24 hour period one or more times a year. (See Appendix I, Exhibit 8). Other special counts may be taken; for example,

New York was tabulating turnstile counts from 8:00 P.M. to midnight and from midnight to 4:00 A.M. daily for many months after the placement of policemen in all the trains and stations during these hours to see what effect such security measures may have had on riding. These are not done, however, as a regular practice nor were they used in this case for scheduling but were rather done at the request of and for the perusal of the Authority Commissioners.

Home Interview Origin and Destination Surveys have not been employed, in those cities where they have been taken, by transit systems for schedule construction. O & D Surveys are sometimes used in the planning of rapid transit extensions, but usually to measure the loading on a pre-determined route, rather than to determine the route itself (which has in the past been determined primarily by political considerations, available railroad rights of way, plans that have been in existence for 20 or 40 years, and needs or volumes too apparent to the naked eye to be first unearthed from O & D data). The transit systems themselves take no O & D surveys in home interviews; the previously described postcard surveys do, however, contain information on origins and destinations.

Mechanical devices installed underneath the steps of a few buses were tried as automatic on-off counters by Cleveland several years ago. They were found to be too expensive for the data provided.⁸

A new attempt at such a device is now being made as part of a Federal demonstration project.⁹ Dr. Samy Elias

is overseeing the project, and the devices are expected to be tested in New York in 1969.

Running Time Counts

Both street conditions and passenger loading vary through the day and over different lines. On surface (bus or streetcar) operations, the scheduled running time is a close measure of the actual running time - in theory - on a normal day. In addition, time at the terminal in excess of the minimum allowed by the contracts is sometimes scheduled to absorb lateness due to abnormal congestion. While it is important to the transit system to schedule sufficient time on the street and in the terminal to allow on-time performance and to avoid excessive overtime payments to the operators, it is also important to schedule no more than is necessary (particularly in the peak hours) so as not to waste men and equipment. In order to determine these running times and terminal (layover) times, as well as to check the performance of individual operators and to check on excessive delays, most transit systems conduct running time counts.

The most common method of observing running time is to station checkers at pre-determined points on the street and to compare their notations, following the progress of each vehicle on paper. This method has an important drawback, as Robert Pollock, until recently head of the Schedule Department in Cleveland, points out: "It is very important to know how the operator handles his vehicle, i.e., if he wastes time in slow starts or slow stops, if he deliberately misses traffic lights, and if he loafes along to "kill" time."10

Sudden surges in loading, or street congestion between observation points, would also go unnoticed. Thus some systems, as Cleveland, use a variation of the previously described on-off count instead, having the checker ride the bus for the length of the route.

The manner of determining and controlling adherence to the running time is, in fact, markedly different in the three systems focused on in this study. Cleveland, as might be expected from the above quotation, takes on board running time counts. There is no regular pattern to these counts, and once a series of running times is established no further checks may be made for years unless reports are made by passengers, employees or street supervisory personnel of deficiencies, or a traffic checker notices excessive lateness. The running time counts are studied to derive an average time corresponding to that taken by the majority of drivers. A unique and severe penalty is meted to any driver found running ahead of time: for each minute he is observed ahead of time, he is docked one day's pay. This method is very effective: the only schedule deviation problem is lateness due to traffic.¹¹

Terminal times in Cleveland are consistently sufficient to absorb the day to day variation in delays due to street congestion, weather, etc. On lines most affected, such as the Clifton Express, 20 minutes and longer terminal layovers are permitted (this is not so in Boston and New York), and any reports of vehicles arriving too late at a terminal to make the next trip out on time are promptly

checked and ameliorative measures taken. The one exception is that layover times are generally not scheduled for bus lines terminating in downtown Cleveland's Public Square, because of the City's consternation at the large numbers of buses there already in rush hours. Sometimes this results in late departures from downtown on these lines.

When a bus is reported excessively late headed for his outer terminal, Cleveland will attempt one of two remedial moves: either a bus will be sent to the terminal from the garage to make the scheduled interval, and, when the substitute bus meets the outbound late bus, the drivers will change buses; or, if supervisory personnel are on the street and riding is not too heavy, a bus (perhaps the late one, perhaps one behind him) will be turned to fill the gap.

There are no penalties in New York for running ahead of time, and remedial measures are employed only in rare cases where delays are extensive.

In New York, running time counts are made on the street, and in the subways, on the platforms. Operators usually know when these checks are being made, and on lines or at times when scheduled running time is loose, operate more slowly than they would normally. At other times, when no checkers or supervisory personnel are on the street, many operators run ahead of time and gain additional terminal time to relax. In the subways, they are simply held to their scheduled time at each dispatching point.

Most bus lines in New York operating on congested streets and handling large passenger loads are given too

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little running time in rush hours, and, in case of more than average traffic delays, too little terminal time at both ends as well. The Authority has several lines in Manhattan with 40% of their buses not being able to leave their terminals on time.¹² As a result of this, and of some drivers running ahead of time, the deviations from schedule are further aggravated by distorted headways, as in the following examples:

a) An example of distorted headways resulting from traffic congestion and heavy loading, coupled with inadequate terminal time, in a Boston setting.

Suppose a traffic queue begins to build up on Massachusetts Avenue, south of Boylston Street. At the same time, several huge trailer trucks enter the queue, further backing up traffic. The result could easily be that while the 4:15 P.M. bus from Dudley reaches M.I.T. at 4:35, the 4:20 from Dudley reaches M.I.T. at 4:50, being then further held up by heavy loading and crowds at M.I.T. and from the factories. Meanwhile, the 4:15 from Dudley has left Harvard Square on time at 4:55 P.M., while the 4:20 from Dudley meets a new queue at Lafayette Square, the result of traffic from Prospect Street backing up across Central Square. The driver of the 4:20 bus, having battled traffic and crowds for almost an hour, must unload and load and leave immediately at Harvard Square at about 5:15 P.M. with no rest, and on a 20 minute (instead of scheduled 5 minute) headway.

It is, in addition, not at all uncommon for this situation to be further complicated by crowds at M.I.T.

headed for Boston and a queue over the Harvard Bridge, so that by the time he reaches Auditorium station, the driver of this besieged bus is due to be leaving Dudley on his next trip - and finds 150 people waiting for him at Auditorium station. He is also apt to find himself at the head of a queue of three or four buses.

b) An example of distorted headways resulting from poor schedule control alone, with no traffic congestion and evenly distributed passenger arrivals.

Driver 1 proceeds slowly in order to stay within the scheduled running time. Driver 2 proceeds at the normal speed of the automobile traffic on the street, and soon catches up to, or gets closer to, driver 1. Driver 3 finds his headway slowly increasing, as driver 2 gets ahead of schedule, along with the crowds in his bus, at the bus stops, and the time spent at each stop loading and unloading passengers.

This slows driver 3 down and further increases the gap between bus 2 and 3, so that eventually bus four and perhaps bus 5 catch up to bus 3. There are now three buses operating in tandem, etcetera. The problem is complicated by the tendency of many drivers at the head of queues to continue to stop at each bus stop, and the reluctance of drivers behind him to pass him and arrive out of place at the terminal.

The end result is the massive bunching of buses (queueing or tandem operation) which frequently produces letters to the editors of New York's leading daily newspapers.

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G. F. Newell and R. B. Potts have developed a model which simulates the bunching of buses.¹³ Based on queuing theory, it requires parameters which, with certain modification of the equations, are readily available as data in transit system files; although the method as it stands requires the measurement of arrival and departure rates at each bus stop. A simplified version did, however, achieve the result of a two-bus bunch at M.I.T. as the result of a two minute delay on the first bus leaving Auditorium, with a scheduled five minute headway.

On the subways, excessive lateness will result when equipment, signal or human failure causes delays. One such delay on a trunk line in the rush hour can hold up dozens of trains and make on-time departure from the terminal impossible. Headways are thus spaced until arrivals approach scheduled time once more. The Schedule Department views this problem as one of maintenance or supervisory failure, and claims no responsibility. No accurate count of the extent of this lateness problem is possible, since terminal sheets listing train arrivals, departures and car numbers are often hopelessly garbled during such delays, and wayside dispatching sheets - all of which are turned in to the executive offices daily and stored for months at a time but rarely referred to - often bear little comparison from one station to another.¹⁴

In non-rush hours, scheduled running times on the rapid transit system are generally loose, but there is no regular pattern. Running time counts are not often taken, and times on "terminal" or "gap" (wayside) dispatch sheets

are unreliable because of a tendency to check the scheduled times, even when trains arrive early and are held to time.

Whereas New York and Cleveland both list from two (New York) to five or six (Cleveland) different sets of running times, depending on time of day, at timepoints along each route, Boston prefers a simpler approach. It has no timepoints. Drivers generally operate at good speed from one end of the line to the other without looking at their watch. There do exist theoretical end to end running times which do not appear on the MBTA's schedules or work programs, and they are generally greater than those observed. Actual Terminal layover times, however, are ample - sometimes approaching 40% of total end to end scheduled time.¹⁵ There is no consistency to this, however: there are cases, primarily the most congested and most heavily used routes, where the combined running and terminal times are inadequate in the rush hour.¹⁶ Terminal layover time is generally not provided on feeder bus lines at the rapid transit terminals, or on the streetcar subway at downtown terminals. Timepoints of reasonable accuracy do exist on the rapid transit lines. It should be noted that the average length of the MBTA's bus lines is shorter than that of New York or Cleveland.¹⁷

Other methods for measuring and determining running time are used in scattered systems. Worthy of mention is the mechanical device affixed to a few buses at a time in Stockholm, which records distance traveled and running speed simultaneously along with time in seconds on a roll, similar to a cardiograph. Overlays for each line are then

used to determine actual running time between specified points; any excessively slow or fast running, congestion, etc., can be seen on the roll, just as if an observer were on board taking notes.

The information is transcribed onto data sheets and then into bar graphs showing the amount over or under scheduled running time which each vehicle actually consumes. These data sheets and graphs show¹⁸ that Stockholm's schedules have the same characteristic of those in Boston and New York: drivers operate ahead of schedule in non-rush hours, particularly in the evenings.

Reports from Supervisors, Dispatchers, Inspectors

Cleveland relies to an important degree on reports from their personnel in the field (as well as on reports from the operators and passengers) to catch discrepancies, over-loads, delay situations, and other schedule inefficiencies. In a great many, though not all, cases, this works well. The viability of this method in Cleveland is due to several factors: foremost is the practice of immediate schedule correction ("patches") without waiting three or six months for the next schedule pick.¹⁹ Thus such reports are acted on at once and not filed. In addition, as alluded to in previous descriptions (see pages 38 and 39), Cleveland has a generally stricter control system, not only in numbers of men (there are only 31 supervisors and inspectors on the street in peak hours)²⁰ but in the emphasis laid upon efficient schedule performance.

In New York and Boston, while there are personnel on the streets for ostensibly the same purpose, as well as

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the records kept by dispatchers on New York's subway (described above), there is neither the emphasis on schedule efficiency nor the practice of feedback from the supervisory personnel to the schedulmakers. The dispatchers and street supervisors handle overloads, delays and so on - when they notice them - on the spot, and it ends there.

Schedule Specifications

With the relevant surveys (or checks or load counts) and running time counts gathered, the headway (frequency in minutes between vehicles or trains) and, in the case of rapid transit service, the number of cars per train, is determined for the 24 hour day at the peak point in each direction. This set of scheduled headways is built, based on a set of objectives for load standards and on constraints of maximum allowable headway (both inconsistently applied in New York and Boston).²¹ In New York, the Rapid Transit load ratio (ratio of passengers to seats, usually expressed as a percentage) at peak load points above which service adjustments would be made is 150% at all times. Of course, in the rush hours, the limitations of capacity produce much higher ratios. At other times, there is a wide variation in load factors, from 50% to the stipulated 150%. On the Bus lines, the schedule load factor is, in theory, 150% for the rush and 115% for the non-rush.

In Boston, the theoretical load factor for the rush hour is 150% and for the remainder of the day 100% (seated load) or less, for the bus lines. In actual fact, rush hour load ratios vary from 100% to 200%, and many lines run with

empty seats in non-rush hours (see reason for this in description of run-cutting). Standees in non-rush hours occur only as a result of abnormal loads, due to late store closings, special events or weather.

Both New York and Boston apply these criteria on an average basis, to time periods of from 15 to 30 minutes, and over the length of rapid transit trains, not to individual cars in the train. In Cleveland, where load factors on the bus lines are 130% rush hour and 100% or less at other times, the factors are applied to smaller periods or individual buses. It is thus extremely rare to see a 53 seat bus in Cleveland with more than 70 people aboard,²² and the general load factor on most lines is nearer 110% in the rush hour. The actual load factor on the rapid transit lines is also, with possibly the exception of an occasional train at the height of the rush hour, about 110% (compared to about 325% in Boston and 400% in New York).²³ Thus in Cleveland, unlike most cities its size, nearly everyone using transit to or from the downtown area gets a seat for the full length of his trip. This is true of non-rush hour small peaks, as on late store closing nights, as well. New York and Boston appear to tolerate an average 150% load factor on these evenings on many lines, while Cleveland runs a separate schedule and provides seats for all riders.

New York runs a maximum headway on all its subway lines of 20 minutes, even in the "owl" or "hawk" hours (1:00 to 5:00 A.M.); some bus routes in New York go to 40 or 60 minute headways in the owl hours and most continue to run;

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all subway lines, with one or two stations excepted, run 24 hours. In Boston, a maximum headway of 30 minutes, with 45 to 60 minutes on marginal bus routes, is maintained; on the subways, 15 minutes is the maximum. There is no owl service at all; it was discontinued in 1959 as an economy move. Cleveland's maximum headways are similar to Boston's; they do run Owl service on 15 lines, with 30 or 60 minute headways.

The headway table is then built into a schedule by progressing outwards to both terminals, using the running times determined in the manner previously described. This gives the arrival and departure times through the day at each terminal. The next task is to link the individual end-to-end trips so as to build "blocks." A block is a series of half - (one-way) or round trips performed by a single vehicle and by one or more driver. In order to do this, each departure and arrival time at the terminal must be matched, allowing the terminal layover time determined through minimum contract requirements (10% of running time in Cleveland, 3 minutes on bus and 15 on rapid transit in New York) and through previously described procedures to allow recovery from possible delays enroute. Where more trips are leaving a terminal in a given period than are arriving, "put-ins" or "pull-outs", usually from the garage but sometimes from other lines, will be indicated. Similarly, when there are more arrivals than departures (as at the end of the rush hour), unneeded vehicles will be "laid-up", or "pulled off" to the garage. The arrival and departure times at the garage and the running times to and from the

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terminal are usually indicated on the schedule.

Not all trips may be built out from the peak load point to the end terminals of a line. Where traffic checks show that all vehicles are not needed for the length of the lines, and where it is accepted practice (it is not in Boston), some will be scheduled to terminate short of the end(s) of the line either to run off (i.e. lay up) to the garage or to return in the opposite direction. Such scheduled turnbacks at a point short of the end terminal are known as "shortlines." A variant of this procedure is to branch a mainline at an intermediate point, operating to two end terminals. With either procedure, the headway beyond this intermediate turning or branching point is less (usually half) than the peak load point headway. Sometimes the vehicles operating from the end terminal will be scheduled to operate express once they pass the intermediate shortline terminal. In this case, few passengers on the line actually experience the combined headway shown at the peak load point. Boston operates very few such express services presently (a number of others were eliminated during the years 1959-62) and New York operates none at all.

Cleveland, however, operates an extensive series of such express services. Donald Hyde, for many years the General Manager in Cleveland, as well as his associates in the schedule department, believed that such express service, more than the frequency of service or the fare, was instrumental in attracting additional riders to the system.²⁴

When the rapid transit line was opened in 1954-58, most ex-

press routes to downtown were retained. On those which passed through a feeder terminal, nearly all the passengers remained on the bus rather than transfer.²⁵

Thus an important element of the schedule specifications is the route description for each major route, shortline, branchline, express line, etc. One line may have a dozen different such route specifications.

Not all schedule specifications are based on matching predetermined objectives and constraints with traffic checks and running time counts. Sometimes management will direct a change for either political or economic reasons. An example of the former is the resistance of the Downtown Brooklyn Merchant's Association to reductions in Lexington Avenue subway service in non-rush hours to Brooklyn, although the trains run with only about 50% or less of the seats filled past the peak load point. An example of the latter is a 1966 directive to New York's rapid transit schedule department to increase headways on certain lines from 8 to 10, 10 to 12, 12 to 15, etc., to free more cars outside the rush hours for badly needed maintenance. With the route and schedule revisions of November, 1967, this change was extended to additional lines. Load factors and other such data did not enter into this decision.

All of the systems studied either treat their objectives inconsistently, sometimes conforming to them, sometimes not; or do not have criteria that they can explicitly state. Cleveland is more conscientious than New York and Boston about both establishing and consistently adhering to such criteria as guides for schedule efficiency. Where other,

arbitrary considerations are imposed by higher levels of management, the results are not always in the best interest of the company; and the initiative and morale of the schedulermakers is visibly sapped, reducing them for the most part to the role of clerks. This is evident, among other places, in New York.²⁶

Run Splitting

The schedule forms the basis for public timetables and for effective street supervision and control. In order to distribute the trips scheduled by each vehicle amongst the operators, it is necessary to cut or split the blocks and assemble pieces of work or whole blocks into eight hour workdays for the drivers, conductors and motormen.

Because of the larger number of vehicles on the road in the two morning and two evening rush hours, a practice long established in the transit industry has been to schedule a certain percentage of runs (a run is a day's work for an operator) as "swing" runs. These runs contain a few hour's work in the morning rush hour, and a few more in the evening. The total time the operator is on the property can be as much as thirteen hours; this is known as the "spread." In general the man is not paid for the first few hours of spread; beyond that there are spread "penalties", or allowances, or guarantees: extra pay for hanging around the property. The pay usually increases from part of the full wage rate to the full hourly wage as the spread increases.

Runs which the driver works more or less continuously for eight hours (or less, but for which he is paid eight hours)

are called "straight" runs. Runs for which he works only four or six hours and is not paid the full eight hours are called "trippers", or "extras."

In recent years the trend in labor contracts has been to reduce the allowable percentage of swing and tripper runs. This is a costly trend, as it means that in at least some cases, some runs which were accomplished by one man must be split into two straight runs, each with less than eight hour's work; or that a tripper run must be paid for eight hours. In New York, in exchange for the ability to use road motormen as yard motormen (to prepare trains and bring them in from yards to the terminal), management has eliminated swing runs on certain subway divisions. The diseconomy is not so apparent in this case because it is masked by assigning all employees to preparing and transferring cars (whether needed or not) and lengthening lunch hours to fill out the eight hours.²⁷ But the effect is clearly seen in Cleveland, where a change last year from 45% to 50% straight runs required fifty additional drivers to give the same service.²⁸

The objectives of efficient run splitting are first, to use a minimum number of men to provide the specified service, and second to minimize the overtime, guarantee (difference between eight hour's pay and less than eight hour's work), spread penalty, and other such costs. In dividing the blocks amongst various employees, the usual practice is to start from both ends of the schedule (first A.M. runs and last night runs) and work inwards building straight runs from

the various possible combinations of pieces of work (a piece is that part of a block extending from one relief point to the next relief point; a relief point is any pre-determined point on a route where a driver can be relieved by another or can run off to a garage), using swing runs to absorb the remaining pieces of rush hour blocks.

Additional constraints must be incorporated into the runs as they are built, such as lunch hour and report and sign-off time. The latter is provided for the operator to exchange any fare reports, transfers, tools, etc. that he may have. Lunch relief as such is no longer required on the Cleveland system; requirements for lunch are generally minimal - the longest contract lunch hour is 35 minutes in New York. It may, of course, be convenient to schedule longer lunch hours in combining pieces of work to form a run.

A good run-cutter enjoys and is adept at juggling a set of runs to reduce overtime and spread penalties, and at fitting remaining pieces of work in without creating new runs.²⁹

The process of run splitting as described above is considered by many in the industry to be of key importance in the efficient operation of the system; often more emphasis is placed on it than on evaluation of traffic and running time counts in seeking an economic operation. A number of attempts have been made in the last decade to computerize the run-splitting procedure, sometimes by electronic data processing companies such as I.B.M.,³⁰ sometimes by consulting firms or individuals. Most have met with failure because of

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the large number of variables involved and the lack of understanding of the intricacies of run-splitting on the part of the programmers. The most successful effort has been made by Samy E. G. Elias and is described in several Demonstration Project reports.³¹ Mr. Elias' work has been extended by several others in application to the schedules of the Manhattan and Bronx Surface Transit Operating Authority subsidiary of the New York City Transit Authority (now part of the Metropolitan Transportation Authority) and has successfully reduced overtime and penalty costs on their work programs through computerized run-splitting.³²

In 1967, Mr. John O'Dougherty of the Massachusetts Bay Transportation Authority traveled across the country to find out about the current state of computerized run-splitting. In addition to the progress made by Dr. Elias, he found³³ the Philadelphia transit management optimistic over their results and in the process of installing Honeywell electronic data processing equipment to improve their capabilities. In Cleveland, as the author also found,³⁴ the attitude was very pessimistic; it was felt that the costs of computerization exceeded what marginal gains were to be had. This may in part be because of the high efficiency of Cleveland's present run-splitting procedure.²⁵ Research done at the Carnegie Institute of Technology in Pittsburgh for the Pittsburgh transit system was also not encouraging to the parties involved, according to Mr. O'Dougherty.

Measures of Schedule Efficiency

There are three ways of looking at how efficient a schedule is currently. One is the employee's criteria: he wants a maximum of straight runs, as little work as possible for his eight hour's pay, adequate running time and terminal layover time to obviate his working overtime due to delays, ample meal allowances, and so on. This is certainly quite reasonable from his point of view.

The passenger judges a schedule by how frequent and fast it is; how reliable it is; his chance of getting a seat.

The transit management is interested in providing a given level of service for the lowest cost. Unfortunately, they often will be more interested in lowering cost at the expense of adequate service from the passenger's (or employee's) viewpoint. As Mr. Pollock points out, "In attaining this end, though, it is not always realized by management that a cut in mileage during a period of fall-off in revenue will result in a reduction in patronage much beyond the normal or average fall-off."³⁵ Statistical evidence of this fact will be presented later in the thesis (see Chapter 5).

Omissions of Method

The foregoing description of the present method of schedulmaking in the transit industry presents a number of shortcomings and omissions. Filling these holes while making the method more consistent and systematic is the goal of this thesis. Therefore, the major omissions and inconsistencies are highlighted below:

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1. No system, Cleveland included, takes into account the changes in usage resulting from changes in schedules and routes; there is no method being used or developed which can predict this phenomenon for changes in existing service or route patterns. Indeed, the majority of the industry feels that they are dealing with a more or less service-inelastic demand for their product. While they recognize that declines in riding do occur following a fare increase,³⁶ they do not believe that riding will either increase or decrease because of changes in service. Those in the transit industry who think it does believe there is no way of predicting such changes.

Data in Boston and New York's files, collected through traffic checks, revenue audits and other observations, show that changes in service do have an effect on riding, sometimes enough to wipe out any gains in operating cost. While the data are not the result of controlled experiments, they nevertheless do lend themselves to simple analysis and a rough set of rules for estimating these changes. (see Chapter 5).

2. In part because of the above omission, there is no regular pattern of followup checks and control measures to test the results of changes that are made. Cleveland is better in this respect than Boston and New York; but the followup data in Cleveland is used to confirm the obtention of the desired results, not as a basis for estimating the results of future changes of a similiar nature.

3. There is no general practice of feedback from the run splitting to the schedule specification steps, although

the same men usually do both. Once the headway, running time and routes are set, the runs are usually cut without further changes in specifications. Sometimes times may be changed here or there by a minute or two; in Boston and on New York's "MaBSTOA" division, excessive non-rush hour service between the A.M. and P.M. peaks is often scheduled because of the recognition that the men involved have nothing to do otherwise in that period. But there is no regular pattern of feedback.

The examples in Exhibits 9 and 10 clearly show that a great deal of manpower time is available outside of the rush hours. By running shorter trains on shorter headways, no mileage increase would be incurred, and the manpower is already being paid. This is a case where the above described feedback could profitably be used.³⁷ Another case might be a route with a long running time. Alternative routes will sometimes have running times that fit, in three or four round trips, more exactly into an eight hour day than the present route, which may require excessive guarantee or overtime payments.

4. The scheduling process itself does not normally involve computing the costs. The schedule department computes mileage figures, and thus does not make use of the balancing between costs and revenues for alternative changes that might give it better insight into the efficiency of its changes. (Costs are normally computed by the accounting department, except in Cleveland; but none, as was indicated earlier, computes revenue changes).

5. New York and Cleveland do not use added cost (marginal cost³⁸ of added or removed service) as a basis for their cost calculations. Many use rule-of-thumb average which include a number of fixed costs. Boston uses an added cost per mile figure, distinguishing it from a "movement cost" per mile figure which is higher, and computes the platform wages (cost of the operator's time and benefits) separately. However, neither Boston nor any other system varies their added mileage costs with the speed of the service in question, although cost data from the New York system indicate a definite reduction in cost per mile as average speed increases.³⁹

6. Potential trips - trips not now served by transit in an area already served by the transit system - are ignored. No use is made of origin and destination data culled from home interview surveys to seek out directional trip volumes with a poor modal split from the transit management's viewpoint. This is again in part because of the reluctance of transit management to believe that such additional services could attract anyone not already using the transit system. While this reluctance is justified in certain cases, there are many possibilities for viable new services that are overlooked.

7. No provision is made on most systems in the scheduling process for matching feeder bus and rapid transit or bus and intersecting bus line headways for convenient transfer connections. Some systems, as in New York, have two entirely separate departments for surface (bus) and rapid trans-

it (subways) scheduling. Cleveland, in an exception to this rule, does schedule all its feeder bus headways in non-rush hours as multiples of the rapid transit headways, and avoids scheduling missed connections at the stations; but they do not schedule either consistent headways or connections on intersecting bus lines. The result in most cities is an interweaving fabric of lines each operating as an independent fiefdom as far as the passengers are concerned. In Boston, where about 50% of all bus riders transfer to the rapid transit lines, and another 30% to other bus lines, it is not uncommon to have a feeder headway of 9 minutes and a rapid transit headway of 10, or 8 minutes.⁴⁰

New York's extensive subway system and frequent headways on most bus lines makes transferring much less of a liability for the passenger. The percentage of feeder riders is much lower, and the major divisions on the subway run the same headway on all lines in the non-rush hours with scheduled across the platform connections wherever possible. However, passageway transfer between divisions, and transfer to feeder bus lines at outlying terminals is still subject to the same lack of headway correspondence.

8. The random variation of headways, and in passenger arrival rates with its affect on loading, or of the distribution of passengers through a subway train, is not recognized as important. When average load factors are the criteria for the schedule, however, the variation will not infrequently produce loads or headways far in excess of the

acceptable standards. Knowing the extent of this variation from car to car and bus to bus will help determine, in Doolittle's words, "the excess of seats over passengers which it is necessary to provide under normal conditions to furnish seats for all, at a time of day when a company can best demonstrate to the public that it is acting in good faith in its attempt to serve the convenience and comfort of its patrons."⁴¹

Similarly the effect of such variations on running time and the adequacy of terminal layover time is generally overlooked. While a small percentage of vehicles may, on the average, arrive too late to leave a terminal on time, the effect on queuing of vehicles and gaps in service at certain times of the day may be felt by a much larger percentage of the riders due to the cumulative effects of such deviations.

Omissions in Practice

In addition to the omissions of method, there are a number of discrepancies between the stated objectives and methods and the actual conditions. These include:

1. Vaguely defined criteria with respect to load factors, running time, checking procedure, and so on.
2. Scarcity of non-rush hour traffic checks, especially for weekends and late at night.
3. Inconsistent application of stated objectives.
4. Lack of initiative resting with schedule department.
5. Most surveys only at the peak load point.

6. Tendency to ignore special events and even, in some cities, late shopping nights.

7. Running time and Terminal time too tight in the rush hour, too loose at other times.⁴²

8. Tendency to look on lateness from traffic congestion or heavy loads as beyond the control and concern of the scheduling department.

Optimal Scheduling Models

Most of the research done so far in this area, discussed below, does not address itself to the problems and methods surveyed in this thesis. There is, however, in progress at the time of the writing of this report a Mass Transit Demonstration experiment entitled "Systems Analysis of Transit Routes and Schedules" in Washington, D. C.⁴³ At first glance this project would seem most appropriate to the questions concerning this thesis.

Unfortunately, it has been learned that the essence of "systems analysis" for this project is the analysis of the entire system at once, using a minimum-time and distance coded network similar to that used in highway planning.⁴⁴ As the next chapter will describe, systems analysis is not defined properly in this manner.

Even ignoring this constraint, the model being developed will be seeking to create an optimum or at least better, configuration of routes and schedules using post-card survey information gathered in 1966 and distributing the passengers over the system to achieve minimum total

waiting times, or minimum costs of service subject to certain constraints, or some similar objectives. An important assumption of the model is that no matter what changes in service are made, the total passengers traveling by transit between each origin and destination zone will remain constant.⁴⁵

This assumption, in the author's viewpoint, totally destroys the validity of the model. Chapter 5 demonstrates the significance of knowledge on the sensitivity of demand to changes in service. By ignoring this sensitivity, any optimal configuration arrived at will immediately be out of phase because of unexpected increases or decreases in riding on various lines. For example, a route extension into a suburb beyond a terminal point will be assigned only those passengers now driving or being driven to the present terminal of the line.⁴⁶ Since the system plan that would include such an extension would require utilization of the existing fleet, the overload that would occur in actual practice would require taking a bus from some other service supposedly at an optimum in the system configuration in order to serve the new route.

There are a number of other inadequacies in this model. Since only inbound trips were surveyed in the postcard survey, manual estimates of the origins and destinations of outbound trips are being made according to trip purpose distribution. Assignments being made on a minimum time basis are using a weight factor of 2.5 for wait and transfer times, with a factor of 1.0 for walk and line-haul times.⁴⁷ These and other arbitrary assumptions, applied

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uniformly over the whole system, smooth over important variations peculiar to individual lines or areas.

The major output as of the spring of 1968 has been a vast number of maps showing time and distance and headway for each link in the transit system, or showing origins and destinations from or to given zones or sectors to other zones and sectors. The latter is certainly a useful tool for analysis, although it is derived from the postcard survey and not a product of any optimal scheduling method. The former is based on information from D. C. Transit System communicated to the consultant. The running times and headways being used are scheduled, not actual times. Chapter 7 illustrates how these parameters can in actual performance be quite different from the scheduled specifications. Since passengers make their decisions on the basis of what they experience, not what the transit company would like them to experience, this could introduce a serious error into the model on some lines, depending on the difference between scheduled and actual conditions. In addition, the coding of all this information is being done by only a few people who have little knowledge of and do not use the D. C. or suburban Transit systems (the consulting agency is in an industrial park in Virginia)⁴⁸. This means that coding errors are not likely to be discovered, and some of these errors are likely to be important.⁴⁹

Finally, in spite of the considerable flexibility of the network model, only two system alternatives will be considered. The alternatives will be developed by looking

at the postcard survey data maps, talking with local community and political groups, looking at the model output, looking at applications for changes made to D. C. Transit, and studying the street pattern. It will be difficult to apply realistic criteria, when such assumptions as calculating service based on an average load factor over $3\frac{1}{2}$ hours are an integral part of the model.

It is not at all clear that the expense and effort associated with such global attempts are worth the results they produce. A line-by-line or areal analysis, taking due note of the effects on adjoining lines, would reduce the problem to a more manageable scale. The effect of a change on a given line is like that of a rock thrown into a lake: the impact is greatest where it falls into the water, and a circle of perturbations spreads out and dies away from that point. Most of the lake is untouched. In addition, the changes recommended in a complete system overhaul of this sort can rarely be implemented all at once. In cases where there is a time lag, the original premises may change. It seems especially odd that Washington would take this approach now, in light of the rapid transit network now under construction.⁵⁰ While some improvements may be needed now, rather than waiting for the opening of the rapid transit lines, others will be outdated almost as soon as they are effected.⁵¹

An example of a more complex mathematical statement of the scheduling process is R. W. Simpson's work in airline scheduling,⁵² which has been well received by the airlines. No data was available, however, on the variation in demand with changes in service; and the method uses network flow

theory, seeking to optimize over a network of fixed zone to zone movements of passengers, rather than on a line by line basis for varying point to point movements with continuous entry and exit points, as is the case in a transit system. This is not to say that the application of linear programming would be without merit in the transit scheduling process; but the shortcomings of the applications developed so far with respect to the nature of urban transit scheduling place it beyond the scope of this thesis, which is the development of methods of incremental route and schedule analysis.

The output of models such as Simpson's also presents a problem for the urban transit analyst. He finds that for the semi-optimization of vehicle utilization, uneven departure times are most appropriate. Outside of some rush hour services on frequent headways, this concept would be infeasible in urban transit service (or, for that matter, on an air service such as the Eastern Airlines shuttle from Boston to New York and Washington to New York), because of the premium passengers place on regular and - where service is infrequent - easily remembered headways (this was a major selling point of the Eastern shuttle⁵³).

Donald E. Ward⁵⁴ has investigated several optimal dispatching policies. In all the models, it is assumed that the exact number of people waiting to fill a vehicle at any given time is continuously known to the dispatcher, who is continually controlling the dispatches of vehicles. This is not, however, the case in an urban transit system where

many kinds of unpredictable perturbations in demand at stops along the line can occur (see Fig. 1 and Chapter 5, pp. 190-194). He finds that optimal schedules (defined as those yielding minimum passenger delay for a given number of dispatches per time period) give a smaller fleet size over "straight" schedules (equally spaced departures through a time period).⁵⁵ This is similar to the conclusion in Simpson's model, and valid when the arrival rate of passengers along the line is continuously known. Ward also finds, as does Simpson, that in an optimal scheduling process, the frequency of departures is geared to the peaking of demand.

Certain aspects of Ward's models do, in spite of the reservations expressed above, look promising. The Multiple Station Dispatch model (p. 49) might be simplified to use data on passengers per minute at the peak load point. However, further work would have to be done to fit these models to the conditions existing in urban transit systems.

The trouble^h with most of the models of this sort is that while they may be useful for investigating a highly controlled new technology, such as that proposed for the High Speed Ground Transport program, they do not address themselves to the characteristics of existing transit systems. Robert J. Gladstone, for example, has developed a scheduling model for a system where vehicles travel at constant speed, enter and exit the main arteries at high speed, have a capacity of only a few passengers, and are scheduled for departure in response to real-time demands.⁵⁶

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None of these states are true of existing urban transit networks; the latter two would be highly unlikely in any form of controlled, public transportation.

The "transportation problem" form of the linear programming technique is utilized in works by James B. McCord, III⁵⁷ and Michael A. Simonnard⁵⁸. Their models assign optimal distribution over links in a network with predetermined amounts of supply and demand. It is unpaired origins and destinations that are distributed, with the objective being lowest total cost. Demand varies randomly. Obviously, in an urban transit system, origins and destinations are already paired: the choice of pairing is made by the units being transported (passengers), not by the management, and the demand resulting from this choice is not random.

The models discussed above form a good illustration of the dichotomy between practicing management and systems analysis research or operations research discussed in the next chapter. In order to achieve mathematical viability and logically satisfying optimizing procedures, assumptions are made and characteristics specified which have, so far, removed them from consideration as useful tools. Hopefully, future research will narrow this gap.

TABLE 1

Summary Comparison of Schedule Process
in New York, Boston, and Cleveland

	<u>New York</u>		<u>Boston</u>	<u>Cleveland</u>
	<u>Bus</u>	<u>Rapid Transit</u>		
1.a) Rush Hr. Load Ratio:	150%	300%	---	130%
Consistency of Application	No	No	No	Yes
b) Non-Rush Hr. Load Ratio:	100-115%	150%	---	100% or less
Consistency of Application	No	No	No	Yes
2. Maximum Headway, Daytime	40	20	60	30
3. Changes Initiated via:				
a) Public Complaint	Yes	Yes	Yes	Yes
b) Union Complaint	Rare	Some	Rare	Yes
c) Traffic Checks	Some	Yes	Some	Yes
d) Supervisor's Reports	Rare	Rare	No	Yes
e) Arbitrary Policy	Yes	Yes	Some	No
Consistency of Changes	No	No	No	Yes
4. Initiative Taken by Sched. Dept.	Rare	Some	Some	Almost all
5. Before & After Comparisons	Rare ¹	Rare ¹	No	Yes
6. Use of Comparisons for Predictions	No	No	No	No
7. Surveys & Checks:				
Frequency of Daily	6 mos.-Several years		3 mos.	2 wks.-3 mos.
Frequency of Weekend	Rare	Rare	Rare	1 mo.
Frequency of 10P-6A	None	None	None	Occasional
Focus on Rush Hr.	No	Yes	No	Split

TABLE 1 (continued)

	<u>New York</u>		<u>Boston</u>	<u>Cleveland</u>
	<u>Bus</u>	<u>Rapid Transit</u>		
Focus on Changes or Regular Service	Both	Changes	Regular	Both
Location Other Than Peak Point	Some	Few	No	Yes
On-Off or On-Board Counts	Rare	No	No	Yes
8. Criteria for Deciding on Alternate Headways	None	None	None	Match Rapid Hwy. or for 100% load
Coordination of Feeder Bus and Rapid Transit Headways		No	No	Yes
Variation of Headway in Non-Rush Hrs. to Match Load	Some	Little	Little	Yes
Special Sched. for Spec. Events	Rare	Some	No	Yes
Special Routes for Spec. Events	No	No	No	Yes
Separate Late-Shopping Schedules for Schedules for Spec. Loads (Snow)	No	No	No	No
9. Feedback Work Program to Sched.	Rare	No	Indirect	No
10. Running Time Checks: Frequency	Rare ²	Some	No	Yes
Outside (Street or Platform) or in Vehicle	Outside Checker	Outside Checker	Outside Checker	Both Supervision & Checkers
By Whom				
Use of Daily Dispatch Records	No	Rare	No	Yes

TABLE 1 (continued)

	<u>New York</u>		<u>Boston</u>	<u>Cleveland</u>
	<u>Bus</u>	<u>Rapid Transit</u>		
11. Actual vs. Sched.				
Running Time Rush:	Not Enough		No Time-points	OK
Midday:	Some Slack		No Time-points	OK
Evening:	Slack	Some Slack	No Time-points	Occasional Slack
Owl:	Very Slack		No Time-points	(Unknown)
Sched. vs. Req. Rush				
Hr. Term. Time:	Varies-Not always enough		Varies-Some Slack	Ok except not enough downtown
Non-Rush Hrs.:	OK	OK	Excessive	Loose
Adherence to Running Time:	No	No	No Time-points	Yes
Penalties for Running Early:	Rare & Complex	Held by Towers	None	1 day's pay per 1 min. ahead
12. Reliability on Heavy Lines	Poor	Fair	Awful	Fair
Effect of Term. Time on Reliab.	None	None	None	Improves except CBD
Effect of Supervision on Reliab.	Some help	None	Little	Fair
13.a) Estimates of Revenue Changes	No	No	No	No
b) Estimates of Costs: Basis	Total Avg.	Mileage, inc. some fixed	"Movement Cost"	Mileage & Platform Hrs.
Done by	Budget	Dept.	Unknown	Schedule Dept.
Vary w/Speed, etc.	No	No	No	No
14. Use of On-Vehicle Postcard Surveys	No	Rare	No	Yes
O. & D. Home-Interview Surveys	No	No	No	No

TABLE 1 (continued)

	<u>New York</u>		<u>Boston</u>	<u>Cleveland</u>
	<u>Bus</u>	<u>Rapid Transit</u>		
Population & Land- Use Studies	No	No	No	Yes
Revenue/Vehicle Trip	No	No	Rare	No
15. Approximate Size of Schedule Dept.				
Checkers	12	12	5	18
White Collar	14	10	12	16
Approximate Size of Research & Opera- tions Planning	0	0	4	8
16. No. of Vehicles	<u>1967:</u> 2,345	<u>1967:</u> 7,106	<u>1966:</u> <u>Bus & St.</u> <u>Cars:</u> 1,017 <u>Rapid:</u> 232	<u>1966:</u> <u>Bus:</u> 935 <u>Rapid:</u> 88
Annual Mileage (in millions)	66	316.3	<u>Bus & St.</u> <u>Cars:</u> 26 approx. <u>Rapid:</u> 9 approx. <u>Bus & St.</u> <u>Cars:</u> 10 <u>Rapid:</u> N.A.	<u>Bus:</u> 27.6 <u>Rapid:</u> 4.2 <u>Bus:</u> 4 <u>Rapid:</u> N.A.
No. of Depots	10	N.A.		
Annual Passengers (in millions)	434.2	1,298.5	200 approx.	<u>Bus:</u> 90 approx. <u>Rapid:</u> 17

This chapter has described the existing methods of Schedule and Route Planning and analysis in urban transit systems, and outlined the shortcomings of these methods. More mathematical statements of the scheduling process developed for the airlines and on a theoretical basis were surveyed to illustrate their shortcomings and potential with respect to the urban transit problem.

With the above groundwork laid, this thesis will now proceed to attempt to improve on the methods described in this chapter.

Footnotes

1. This type of error can be easily found in many MBTA checks. The method of detection used by the author is to note the abrupt disappearance for one round trip of a vehicle in a sequence of several vehicles and on a regular schedule, and to seek the vehicle listing under another line--where it is usually to be found, at about the time a vehicle on the line from which it is missing would be expected to pass. A missing or extra vehicle number, double or half headway without a double or half load, or an abnormally high or low count on a particular vehicle are all clues to this kind of error. (The MBTA does not apparently attempt to eliminate these errors, as they are invariably included in the summary sheets.)
2. The author found, in examining 1967 and 1968 Traffic Checks in Cleveland on principal lines, several instances of checks being taken at outlying locations to determine the usage of branch lines; and repeated instances of half hour or one hour checks at terminals and other odd locations in response to reported problems.
3. The on-bus Postcard survey punch cards for all MBTA lines were listed and examined by the author. Frequent errors and omissions, by both passengers and coders, were discovered in certain of the questions. For example, many passengers did not understand the "mode from station" question and indicated "walk," thinking of their final mode, rather than "subway" as their continuing mode. Coders occasionally punched incorrect digits in the origin or destination zone and subzones, or processed cards from a different line as part of a given line's data. Many of these errors can be eliminated by analyzing by hand; computer analysis would retain them.
4. No Boston area transportation planning body, consulting agency or university, including the MBTA, contacted by the author in the past few years has even had available any listing or summaries of the postcard survey data.

5. Bi-State Development Agency of the Missouri-Illinois Metropolitan District and Bi-State Transit System, The Radical Express and Suburban Crosstown Bus Rider, United States Department of Housing and Urban Development Mass Transportation Demonstration Project INT-MTD-8, Final Report, p. 5. See also Chapter V, this thesis, p. 184.
6. Transit Record, monthly publication of the New York City Transit Authority.
7. In the five years of researching the MBTA's scheduling process, and the thirteen years of researching New York's rapid transit scheduling process, the author has never seen, in his many visits to the respective scheduling departments, this revenue data in use or in the files of the scheduling department, nor been told that it was currently in use. New York does use such data to measure the "profitability" of bus lines, i.e., the revenue per mile operated, and the trends of growth or decline.
8. According to Mr. George Ihnat, Director of Research and Planning, February 27, 1968.
9. Federal Demonstration Project WVA-MTD-2, "Automatic Passenger Counting Devices," Approved 1/31/67, Expected completion 1969.
10. Robert T. Pollock, "Traffic Checking and Schedule Preparation," Chapter XVI in Principles of Urban Transportation, ed. Frank H. Mossman (for the American Transit Association), (Cleveland: Western Reserve University Press, 1951), p. 146.
11. Once past a specified point (usually the peak load point) on each line, the operator is allowed to run "free" to the terminal, and may thus run ahead of schedule on this portion of the route without penalty.
12. According to Special Traffic and Running time checks made by the Transit Authority on the M-3 (49-50 Streets) route on November 9, 1966 and on the M-15 (1st and 2nd Avenues) route on November 10-14, 1967.
13. G. F. Newell and R. B. Potts, "Maintaining a Bus Schedule," Proceedings of the Second Conference of the Australian Road Research Board (1964) II, 388ff.

14. Based on examination by the author of several month's worth of terminal and "gap" (wayside dispatching) sheets during the summer and winter of 1966. The discrepancies were greatest on lines experiencing the greatest delays and thus the largest number of turned and out of place trains.
15. For example, Harvard to Dudley bus line midday observed mean running time is 26 minutes, terminal time 19 minutes (42%); Chestnut Hill to Kenmore, observed mean running time 19 minutes, terminal time 11 minutes (37%); Harvard to Lechmere observed time round trip 27 minutes, terminal time 18 minutes (40%). Boston has the lowest number of miles operated per bus per month--1,742, compared to 2,550 in Cleveland, 2,600 in New York, 2,696 in Chicago, and 2,920 in Detroit (1963 company data). (Cleveland's figure is probably lower than one would expect from the efficiency of its scheduling process due to the union requirement of 10% minimum terminal time.)
16. Based on observations by the author. For example, Harvard to Dudley or North Cambridge to Waverly and Watertown.
17. One-way average route length:
 Boston 3.33 ("Line Statistics of Schedule in Effect," MBTA timetable office, 1966).
 New York 5.00 est., 4.50 excluding duplicate (two routes on same street) mileage (Transit Record, op. cit., note 6, August 1967).
 Cleveland 6.50 local, 12.0 express (route data obtained on visit to Cleveland, February 1968).
18. As examined by the author during his visit to Stockholm in July of 1967.
19. A "pick" consists of the posting of new employee schedules (runs) and the process of operators choosing the runs on the basis of seniority. In Boston this takes place every three months, in New York every six on the average. The pick must occur regardless of whether there are changes in operating schedules, in order to update both contracted work rules and seniority preference.

20. Compared, for example, with 87 in the afternoon peak hours in New York for nearly 5 times as many passengers.
21. Based on studies of traffic checks and street observations by the author. For example, on the bus lines entering Dudley station (Boston) in the morning peak hour, the peak direction average load per bus per line is: 42, 45, 45, 52, 54, 55, 58, 59, 65, 69, 76, 87. This represents a range from 94% to 194% load factor (the last is the count in Cambridge on the Dudley-Harvard line). In New York, the 1967 Cordon counts from Upper Manhattan and Queens show a scheduled average load factor per subway train per line from 10:00 to 11:00 AM of: 61, 80, 106, 108, 110, 114, 113, 118, 129, 140.
22. Based on examination of 1967-68 traffic checks and extensive street observations on heaviest lines, week of February 26, 1968.
23. Cleveland's checks show 6,500 passengers in the peak hour, with 20 trains of about 320 seats each serving these riders from the west; from Windermere, the figure is 3,500 riders on 10 trains of 320 seats each. In Boston, the Ashmont line reaches 5,400 to 5,700 passengers in the peak 15 minutes with 20-24 cars (approximately 350%), and over a longer period services about 4,500 passengers with 20 cars per 15-minute period (320%) (MBTA 1967 Traffic Checks). In New York, 1967 Cordon count traffic checks show the Queens IND lines with 230 passengers per 56 seat car (410%) and the Bronx-Upper Manhattan IRT lines with 180 passengers per 44 seat car (410%).
24. About five per cent, according to Mr. George Ihnat, director of Research and Planning. This is on an average basis.
25. Based on observations by the author and statements by Cleveland management.

26. New York's schedule-makers have complained on numerous occasions to the author of their inability to effectively use their own best judgment and observation in constructing schedule specifications, of having to fulfill "orders from above" with which they disagree. They feel they cannot voice their disagreement--and are usually not directly represented in top management meetings which make the decisions on schedule changes. The result of this and the heavy paperwork is an often expressed malaise, a futility of initiative or interest, an "oh well, what can you do" attitude.
27. Based on studies by the author over thirteen years of schedules in New York.
28. Mr. LeFevre, chief run-splitter, Cleveland, 3/1/68.
29. Stated by Mr. J. LeFevre, interviewed on February 29, 1968; also true from the author's experience.
30. In New York about 3 to 5 years ago, no published references known; in Philadelphia, see International Business Machines, Electronic Transit Scheduling at Philadelphia Transportation Company (no date, publ. 1960-61).
31. See, for example, The Use of Digital Computers in the Economic Scheduling of Both Man and Machine in Public Transportation, Kansas State University Bulletin, Kansas Engineering Experiment Station Special Report No. 49; and A Mathematical Model for Optimizing the Assignment of Man and Machine in Public Transit "Run Cutting," West Virginia University Engineering Experiment Station Series 67, No. 3-5, September 1966 Research Bulletin No. 81. Both are technically Final Demonstration reports.
32. Transit Authority working papers show that the computerized run-splitting procedure, compared with a set of runs prepared under similar rules and restrictions in two other boroughs, raised the average hours per run actually worked from 6:49 to 7:32 hours while reducing the average pay per run from 9:31 to 9:12 hours. On nine MaBSTOA routes comprising 16% of the total number of runs, the computer produced a 1.2% reduction in the pay hours while reducing the number of "special" (piece) runs. Cutting all 4,113 runs and printing them took 11 minutes.

33. Related to the author by phone, March, 1968.
34. In interviews conducted February 25 to March 1, 1968.
35. R. Pollock, ibid. (note 10), p. 156.
36. Although the prediction usually follows the gross system decline formula of Simpson and Curtin--see John F. Curtin, "The Effect of Fares upon Transit Riding," paper, 47th Annual meeting of the Highway Research Board, Washington, D. C., January 1968 (see Chapter V, page 159).
37. New York's schedule-makers point out that shortening trains in the non-rush hour midday would require additional men to transfer cars to and from yards at the terminals, sufficient to offset the economic advantages of such a practice. However, the author has made calculations which show that in spite of this, there are cases where the alternative should still be considered (See Chapter VII, pp. 308 and 328 .)
38. See Chapter III, page 110 and Chapter VI.
39. Alex Friedlander, Marginal Variable Costs per Subway Car and Bus Mile on the New York City Transit Authority System (Brooklyn College of the City University of New York, 1962). Reference is made to this, and more recent data introduced in the chapter on costing.
40. For example, in the evening on the Arlington Heights bus from Harvard and the Harvard-Ashmont subway. This line is not the best example because for most of the day it is one of the only MBTA lines with the same headway as the rapid transit connecting line. On Sunday evening, this same bus line, however, operates on a 15-minute headway while the subway is on a 14-minute headway.
41. F. W. Doolittle, Cost of Urban Transportation Service (American Electric Railway Assoc., 1916), p. 116.

- 7
42. In a letter from the late Charles L. Patterson, Chairman of the New York City Transit Authority, to Mr. Jason Fane, dated November 14, 1960, it is stated that "Currently scheduled running time is not considered to be in excess of a safe minimum, and does, in fact, compare favorably to similar operations in other large urban areas." The author's observations do not bear this out. However, the slack in New York's non-rush hour running times (and especially evening times) is on a par with that observed by the author in Stockholm, and rather small compared to Boston's.
 43. Alan M. Voorhees & Associates, Inc., Systems Analysis of Transit Routes and Schedules, first quarterly progress report, Mass Transportation Demonstration INT-MTD-14 (Washington, D. C., March, 1968).
 44. See, for example, Brian V. Martin, Minimum Path Algorithms for Transportation Planning, Massachusetts Institute of Technology Research Report R63-52, Dept. of Civil Engineering (Cambridge, Mass., December 1963).
 45. Voorhees, p. 10.
 46. According to Joel Miller, project engineer, in an interview in McLean, Virginia, on April 17, 1968.
 47. The author found this to be true in his work on the Queens-Long Island model for Traffic Research Corp. in New York and also in his examination of the data coded by Wilbur Smith Associates for the Boston Regional Planning Project in 1963. See footnote 3, this chapter, and footnote 110, Chapter V. In New York when the author worked on the Traffic Research Corporation Queens-Long Island modal split model in 1965, he found a number of uncoded free transfer points between rapid transit lines in Queens that were a source of distorted predicted passenger loading. In addition, scheduled running times given by the Transit Authority, rather than actual running times, were being used. Correction of these errors resulted in the predicted loads by route corresponding more closely with the actual loads.
 48. The first line is expected to be in service by 1972.

49. For these reasons, New York is planning a staged implementation of changes in its bus routes, with a view towards newly planned subway lines.
50. Computerized Schedule Construction for an Airline Transportation System, Massachusetts Institute of Technology Technical Report FT-66-3, Department of Aeronautics & Astronautics (Cambridge, Mass., November 1966).
51. The scheduled and guaranteed hourly frequency was stressed as an important factor in the success of the shuttle by Eastern Airlines management in a presentation at the Harvard Business School on December 8, 1965. Passenger surveys show that 32 per cent of the riders use the shuttle for this reason (The New York Times, February 3, 1965).
52. Optimal Dispatching Policies by Dynamic Programming, Massachusetts Institute of Technology Research Report R66-55, Department of Civil Engineering (Cambridge, Mass., November 1, 1966).
53. Ibid., p. 6.
54. Scheduling in Constant Speed Transportation Systems, Massachusetts Institute of Technology, Operations Research Center Technical Report No. 34 (Cambridge, Mass, January, 1968).
55. The Transportation Problem with Random Demands, Interim Technical Report #12, Fundamental Investigations in Methods of Operations Research, Massachusetts Institute of Technology.
56. Transportation-Type Problems, Interim Technical Report #11, ibid.

APPENDIX

EXHIBIT I

NEW YORK

% of PASSENGER TRAFFIC by HOURS -- RAPID TRANSIT

Hours	Wednesdays										
	3/25/42	3/10/54	3/7/56	3/11/59	3/16/60	3/15/61	(c) 5/2/62	3/13/63	3/11/64	3/10/65	3/9/66
12:mid. - 1:AM	1.21	.86	.77	.78	.75	.73	.76	.71	.67	.69	.85
1:AM - 2:AM	.66	.43	.44	.43	.43	.41	.42	.41	.42	.40	.39
2:AM - 3:AM	.39	.29	.29	.26	.25	.29	.27	.26	.26	.25	.23
3:AM - 4:AM	.29	.24	.24	.22	.21	.20	.21	.20	.21	.19	.18
4:AM - 5:AM	.38	.34	.35	.31	.29	.29	.28	.27	.28	.29	.27
5:AM - 6:AM	.81	.76	.79	.78	.71	.74	.74	.66	.71	.72	.71
6:AM - 7:AM	3.25	3.61	3.61	4.15	4.09	3.92	3.82	3.99	3.83	3.84	3.62
7:AM - 8:AM	10.29	12.21	12.63	12.28	12.30	11.91	11.85	12.24	11.88	11.88	12.13
8:AM - 9:AM	13.00	13.94	14.48	13.81	13.47	13.49	13.72	13.27	13.22	13.46	13.58
9:AM - 10:AM	5.02	4.92	5.04	4.82	5.04	5.29	5.30	5.12	5.54	5.38	5.34
10:AM - 11:AM	3.46	3.22	3.07	3.22	2.95	3.08	3.06	3.14	3.15	3.09	3.16
11:AM - 12:noon	3.11	2.84	2.63	2.72	2.55	2.70	2.67	2.61	2.68	2.66	2.64
12:noon - 1:PM	3.19	2.83	2.60	2.63	2.48	2.56	2.49	2.53	2.52	2.51	2.61
1:PM - 2:PM	3.24	2.91	2.63	2.75	2.68	2.84	2.67	2.79	2.89	2.94	2.89
2:PM - 3:PM	4.15	4.06	3.83	4.25	3.96	4.37	4.36	4.48	4.50	4.45	3.84
3:PM - 4:PM	4.93	4.92	4.74	5.23	5.02	5.31	5.15	5.12	5.33	5.32	5.07
4:PM - 5:PM	6.91	9.24	9.43	9.68	8.91	9.06	9.55	9.53	9.57	9.15	9.27
5:PM - 6:PM	12.93	15.38	15.59	14.62	14.97	14.18	14.81	14.32	14.30	14.24	14.44
6:PM - 7:PM	7.44	6.68	6.73	6.62	6.95	6.46	6.18	6.27	6.53	6.67	6.93
7:PM - 8:PM	4.51	3.16	3.08	3.22	3.19	3.31	3.04	3.21	3.06	3.16	3.25
8:PM - 9:PM	3.14	2.10	2.10	2.08	2.07	2.10	1.92	2.04	2.03	2.09	2.23
9:PM - 10:PM	2.32	1.76	1.71	1.78	1.70	1.72	1.61	1.60	1.63	1.65	1.71
10:PM - 11:PM	2.47	1.90	1.94	2.05	2.17	2.09	2.41	2.27	2.23	2.19	1.92
11:PM - 12:mid.	1.92	1.40	1.28	1.31	1.30	1.32	1.24	1.25	1.15	1.14	1.33
Hi-turnstiles & Misc. (undistr.)	.91	(a)	(a)	(a)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total Passengers (in thousands)	6,125	4,860	4,589	4,563	4,589	4,676	4,631	4,590	4,639	4,541	4,431
Rush Hours --											
7:AM - 9:AM	23.29	26.15	27.11	26.09	25.77	25.40	25.57	25.51	24.90	25.34	25.71
4:PM - 7:PM	27.28	31.30	31.75	30.92	30.83	29.70	30.54	30.12	30.40	30.06	30.63
Total	50.57	57.45	58.86	57.01	56.60	55.10	56.11	55.63	55.30	55.40	56.34

(a) Included in hourly totals.

(b) During rush hours only on stations where hi-turnstile readings represent over 20% of total station revenue, the readings are included in hourly totals. All other hi-turnstile and train collections are excluded from hourly totals and are represented by the indicated percent.

(c) Hourly passenger traffic study, normally made in March, was taken on May 2 because of exceptional increase in passenger registration on rapid transit lines due to strike on privately-owned bus lines during March 1962.

EXHIBIT 2 - TYPICAL TRAFFIC CHECK (SURVEY), BOSTON

METROPOLITAN TRANSIT AUTHORITY

Sheet No. 1

Form 515-7-49-5m

Date JUNE 2 194 62 Weather FAIR

Taken at ROCK HILL STATION

Taken by Mekhonda

1344 JAN TIME CAR PASS				1345 JAN TIME CAR PASS				JAN TIME CAR PASS				JAN TIME CAR PASS				JAN TIME CAR PASS				JAN TIME CAR PASS				JAN TIME CAR PASS				JAN TIME CAR PASS			
6 ³¹	290	18		6 ⁴²	309	42		8 ²⁵	278	43		8 ²⁸	207	29		10 ³⁶	290	32		10 ³⁷	309	25									
6 ⁴²	223	34						8 ²⁹	307	36		10 ⁴⁷	323	38		10 ⁵⁴	307	46													
	2	52	26						1	43	43		2	65	33		10 ⁵³	278	39												
																	3	109	36		2	71	36								
6 ⁵²	278	46		6 ⁴⁷	307	22		8 ³³	290	31		8 ³⁸	307	48																	
				6 ⁵⁷	207	34		8 ⁴¹	323	15						11 ⁰³	290	28		11 ⁰¹	207	48									
	1	46	46		2	56	28		2	46	23		1	48	48		11 ⁰⁸	200	27		11 ⁰⁷	307	32								
																	11 ¹⁹	323	43		11 ²³	307	30								
7 ⁰³	290	31		7 ⁰¹	309	44		8 ⁵⁵	278	54		8 ⁵⁶	307	50		11 ²⁶	278	24													
7 ¹³	323	26						8 ⁵⁷	307	23						4	122	31		3	110	37									
	2	57	28		1	44	44		1	54	54		2	73	37																
																	11 ³¹	206	22		11 ³⁵	207	58								
7 ²³	278	58		7 ²³	307	70		9 ⁰²	290	16		9 ⁰⁸	307	49		11 ³⁷	290	36		11 ⁴⁷	309	32									
	1	58	58		1	78	70		9 ¹³	222	30		9 ²¹	307	66		11 ⁴⁶	200	24												
									9 ²³	278	35		9 ²⁶	207	21		11 ⁵³	323	25												
7 ³²	290	40		7 ³²	207	32			3	81	27		3	136	45		11 ⁵⁸	278	23												
7 ⁴²	323	32		7 ³⁸	309	34										5	130	26		2	90	45									
	2	72	36		2	66	33		7 ⁴⁰	Relief																					
																	12 ¹⁰	206	37		12 ⁰⁷	307	61								
7 ⁵²	278	27		7 ⁵⁰	307	51		10 ⁴⁹	207	25		10 ⁵¹	309	27		12 ¹³	290	25		12 ¹¹	207	13									
	1	27	27		1	51	51		10 ⁵¹	323	30		10 ⁵¹	307	36		12 ²²	200	30		12 ²²	309	37								
									10 ⁵⁵	278	33		10 ⁵⁹	207	35		12 ²⁷	323	16												
8 ⁰³	290	29		8 ⁰¹	207	31			3	98	33		3	98	33		4	108	27		3	111	37								
8 ¹³	323	33		8 ⁰⁸	309	36																									
	2	62	31		2	70	35																								

Arrived at Dunes

INSTRUCTIONS: Counts to be taken in the following periods: IN 30 min. from 6:00-6:30 A. M. 15 min. from 6:30-9:00 A. M. 30 min. for rest of day.
OUT 30 min. from 6:00 A. M.-4:30 P. M. 15 min. from 4:30 A. M. 6:30 P. M. 30 min. rest of day.

Please record your answers to the following questions, even if you have previously done so on another trip and place the card in the survey card box or give to the survey worker as you exit.

4

➡ At what stop did you get on this vehicle? _____
Station name - intersecting street - or nearest building

➡ How did you get to this stop? (Check One ☒ ☐ Auto ☐ Taxi ☐ Subway or Elevated ☐ Walked ☐ Train
☐ Bus or Streetcar ☐ Other (Explain) _____

➡ Before going to this stop where did you start this trip? _____
Street address - or nearest intersection - or building, etc. City, Town, or Section of Boston

➡ At what time? _____
☐ A.M.
☐ P.M.

➡ At what stop will you get off this vehicle? _____
Station name - intersecting street - or nearest building

➡ After getting off this vehicle, where will you end this trip? _____
Street address - or nearest intersection - or building, etc. City, Town, or Section of Boston

➡ How will you get there? (Check One ☒ ☐ Auto ☐ Taxi ☐ Subway or Elevated ☐ Walk ☐ Train
☐ Bus or Streetcar ☐ Other (Explain) _____

➡ At what time do you expect to arrive there? _____
☐ A.M.
☐ P.M.

➡ What is the purpose of this trip? (Check One ☒ ☐ To or from work ☐ To or from shopping ☐ To or from Social or Recreation
☐ To or from school ☐ Other (Explain) _____

➡ Do you ride (Check One ☒ ☐ Daily? ☐ Weekly? ☐ Occasionally? ➡ Do you have a (Check One ☒ ☐ drivers license? (One ☒ ☐ Yes ☐ No

➡ How many persons are in your household? _____

➡ How many passenger cars do they own? _____
☐ No, I am under 16 years of age

For office use only

TRANSIT POSTCARD QUESTIONNAIRE NUMBER 4

MTA Bus and Streetcar Service

Table 1

3 of 5

Exhibit 3

Mail this card at any mail box if it was not collected at the exit - For information telephone 542-9897 in Boston
YOUR PARTICIPATION IN THIS IMPORTANT SURVEY IS APPRECIATED

BOSTON REGIONAL PLANNING PROJECT, SPONSORED BY THE MASS TRANSPORTATION COMMISSION AND THE MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS, IN COOPERATION WITH THE U.S. HOUSING AND HOME FINANCE AGENCY, AND THE U.S. DEPARTMENT OF COMMERCE, BUREAU OF PUBLIC ROADS.

EXHIBIT 4: ON-BOARD POSTCARD SURVEY, NEW YORK, RAAO TRANSIT, 1967

I 1582

1. I travel by **SUBWAY**:

☐ daily ☐ often ☐ occasionally

FOR:

☐ work ☐ school ☐ shopping
☐ personal business

2. I am going to:

☐ Manhattan ☐ Brooklyn

☐ other

The nearest principal street intersection to my destination is
and

3. I take the train (give letter symbol).

I enter the subway at the **SAME STATION** I used before the Nov. 26th service changes took effect:

☐ Yes ☐ NO.

IF "NO", what station and line did you previously use?

4. After leaving this train I will use the following to complete my trip:

☐ walk ☐ bus

☐ I transfer to the subway train (Give letter symbol) at the station.

☐ other

5. Compared with my previous riding experience:

A. The service improvements:

☐ save minutes on my trip;
☐ have made no difference;
☐ add minutes to my trip.

B. My trains now are:

☐ less crowded ☐ unchanged
☐ more crowded

6. I find your new

MAPS:

☐ helpful ☐ fair ☐ poor
☐ never use a map

STATION SIGNS:

☐ helpful ☐ fair ☐ poor

TRAIN SIGNS:

☐ helpful ☐ fair ☐ poor

7. To help the progress of your long range program for improvement of subway service, I suggest:

.....
.....
.....
.....
.....

Thank you for your interest and assistance.

EXHIBIT 5: TYPICAL DAILY REVENUE BY ROUTE SUMMARY, BOSTON

FORM 11000 METROPOLITAN TRANSIT AUTHORITY

RT.NO.	DESCRIPTION	REVENUE	5 06 63	
			RT.COST	COST %
1301	ASHMONT -ASHMONT VIA NORFOLK & WASH	7.60	128.57	5.91
1302	HALLET SQ - ASHMONT	60.60	106.47	56.92
1304	MORTON & CORRETT STS -ASHMONT	309.22	401.22	77.07
1305	MORTON & WASH STS - ASHMONT VIA WASH ST		21.25	
1309	MORTON & WASH STS - ASHMONT VIA ASHMONT ST	50.30	70.60	71.25
1310	GALLIVAN BLVD & MORTON ST - ASHMONT VIA TALBOT AVE	235.86	350.80	67.23
1311	GALLIVAN BLVD & WASH ST - ASHMONT VIA TALBOT AVE	1.10	9.65	11.40
1313	GALLIVAN BLVD & WASH ST - ASHMONT VIA DOR AVE	12.40	.99	252.53
1314	MORTON & WASH STS - ASHMONT TERM		2.33	
1315	NORTHAMPTON & WASH - SOUTH STA VIA WASH ST	320.77	274.09	117.03
1320	BAY VIEW LOOP - ALBANY GARAGE	677.12	942.87	71.81
1330	PEACEVALE RD & NORFOLK - ASHMONT	6.10	.99	616.16
1331	MATTAPAN - HAYMARKET - PARK ST	3.90	21.03	18.54
1332	E CONCORD ST & HARRISON AVE - COPLEY SQ	62.95	81.86	76.90
1335	HUNT AVE & STUART ST - SOUTH STA VIA KNEELAND ST	27.31	31.83	85.80
1336	FIELDS COR STA - DUDLEY TERM	79.90	158.05	50.55
1338	BOYLSTON & DARTMOUTH STS - BOWDOIN SQ	46.61	133.91	34.81
1339	PIERCE SQ MILTON - ASHMONT		1.22	
1339	MATTAPAN - ASHMONT	179.25	420.35	42.64
1340	SOUTH STA - NORTH STA VIA FEDERAL ST	258.51	153.44	168.48
1341	FIELDS COR STA - FIELDS COR STA LOOP LINE VIA NEPONSET	540.41	1007.41	53.64
1344	KANE SQ - DUDLEY TERM	908.89	781.05	116.37
1345	GROVE HALL - DUDLEY TERM	635.38	469.00	135.43
1346	FRANKLIN PARK PEABODY CIR - DUDLEY TERM	594.42	648.31	91.69

55

EXHIBIT 6

August, 1967

TRANSIT RECORD

NEW YORK CITY TRANSIT AUTHORITY—BUS OPERATION REVENUE PASSENGERS AND PASSENGER REVENUE BY LINES FOR TWELVE MONTHS ENDED JUNE 30, 1967 AND 1966

BROOKLYN BUS

LINE	REVENUE PASSENGERS		PASSENGER REVENUE		LINE	REVENUE PASSENGERS		PASSENGER REVENUE	
	Twelve Mos. Ended June 30 1967	Twelve Mos. Ended June 30 1966	Twelve Mos. Ended June 30 1967	Twelve Mos. Ended June 30 1966		Twelve Mos. Ended June 30 1967	Twelve Mos. Ended June 30 1966	Twelve Mos. Ended June 30 1967	Twelve Mos. Ended June 30 1966
B-1 Manhattan Beach	1,005,725	1,035,677	\$ 185,703	\$ 148,866	B-53 Metropolitan Avenue	5,175,552	5,207,895	\$ 895,554	\$ 887,846
2 Flatbush Ave.-Ave. R	2,263,558	2,359,154	413,693	324,266	54 Myrtle Avenue	826,045	950,543	159,724	135,317
3 Avenue U	1,766,556	1,901,269	324,572	264,127	55 Richmond Hill	4,771,090	5,130,284	897,071	722,350
4 Bay Ridge Parkway	1,214,611	1,351,425	206,893	177,311	56 Jamaica Avenue	4,743,705	5,123,352	874,643	721,993
5 Kings Highway	4,642,256	4,916,653	837,930	676,378	57 Flushing Avenue	4,328,017	4,732,976	830,560	685,376
6 Bay Parkway-Avenue J	6,666,193	6,934,142	1,196,416	930,464	58 Corona Avenue	5,217,458	5,767,587	946,949	855,355
7 Kings Highway-Saratoga Avenue	3,059,217	3,399,445	531,636	457,391	59 Grand Street	1,029,245	1,042,681	196,420	149,902
8 18th Ave.-Foster Ave.	5,444,144	5,824,016	956,455	773,830	60 Wilson Avenue	7,268,162	7,731,707	1,364,517	1,112,121
9 60th Street	2,865,600	3,015,772	461,575	381,897	61 Crossdown	6,859,347	7,430,574	1,309,974	1,072,161
10 New Lots Avenue	5,091,327	5,448,714	985,066	797,111	62 Graham Avenue	3,463,808	3,861,036	653,201	547,547
11 49th Street-53rd Street	1,460,784	1,599,216	258,520	220,737	63 Fifth Avenue	9,593,272	10,890,320	1,847,263	1,540,142
12 East New York Avenue	5,136,098	5,541,603	954,670	782,317	64 86th Street	2,429,201	2,590,563	426,684	350,958
13 Crescent Street	1,396,618	1,421,006	240,956	194,179	65 Bergen Street	4,372,203	5,202,903	810,068	736,153
14 Pitkin Avenue	4,822,031	5,379,264	902,603	761,596	67 Seventh Avenue	3,921,851	4,238,095	729,632	593,536
16 Fort Hamilton Parkway	3,635,394	3,873,058	600,982	500,660	68 Coney Island Avenue	5,879,403	6,293,637	1,058,017	852,600
17 Remsen Avenue	3,344,847	3,586,053	626,478	504,420	69 Vandalia Avenue	2,168,112	2,429,921	352,334	335,202
18 Wyckoff Avenue	952,963	1,007,491	185,331	146,978	70 Eighth Avenue	2,114,506	2,304,542	387,525	322,543
19 Carlton Avenue	468,624	608,900	90,985	88,660	71 Union Street	517,361	551,475	93,420	77,126
20 Decatur Street	1,344,321	1,377,119	220,316	185,878	73 North's Point	2,523,227	2,726,830	471,714	39,169
21 Brighton Beach Avenue	2,093,014	2,292,552	376,175	312,095	74 Smith Street	2,984,633	3,196,150	557,256	453,640
22 Atlantic Avenue	3,074,356	3,397,277	566,986	471,977	77 Lorraine Street	1,345,567	1,445,599	246,737	203,706
23 Cortelyou Road	2,444,459	2,159,178	359,962	293,056	78 Mill Basin	521,729	448,081	68,749	47,128
24-29 Greenpoint-Meeker-Marcy Avenues	1,636,325	1,810,923	309,399	260,176	81 World's Fair Special	—	352,196	—	85,299
25 Fulton Street	3,896,303	4,309,682	755,686	634,617	82 World's Fair Special	—	196,465	—	49,116
26 Putnam Avenue	4,988,562	5,479,087	955,644	794,757	83 Pennsylvania Avenue (from 2/27/66)	661,970	261,781	105,735	26,643
27 Gerritsen Beach	2,100,346	2,206,364	392,315	311,790	Miscellaneous(a)	—	(1,762,876)	—	—
33 Hamilton Avenue	3,967,279	4,299,875	685,247	574,879	Total	262,140,393	281,887,957	\$ 48,339,184	\$ 39,857,221
34 Bay Ridge Avenue	9,048,397	9,825,933	1,680,677	1,369,675	Adjustment of High School Fares	(41,961)	480,824	—	—
35 Church Avenue	5,050,551	5,368,121	889,539	723,782	Unregistered Elem. School Fares (on Monthly Passes)	14,933,344	13,422,578	401,188	374,356
37 Third Avenue	5,521,446	6,030,894	1,044,621	864,241	Unregistered Elem. School Fares (on Federal Grant)	110,500	—	25,352	—
38 DeKalb Avenue	8,027,853	8,533,941	1,500,154	1,220,613	U. S. Post Office Fares	542,432	529,548	168,684	79,436
39 Williamsburgh Bridge	2,512,485	2,716,689	491,852	400,086	Add. School Revenue Payable by City of N. Y.	—	—	9,003,147	6,336,739
40 Ralph Avenue	3,713,072	4,241,260	712,227	617,467	TOTAL BROOKLYN BUS	277,685,708	296,320,947	\$ 57,877,555	\$ 46,647,552
41 Flatbush Avenue	13,823,232	14,577,021	2,605,583	2,103,750					
42 Rockaway Parkway	1,989,525	1,927,759	345,628	258,946					
44 Nostrand Avenue	12,576,911	13,747,476	2,348,055	1,944,088					
45 St. Johns Place	5,109,804	5,648,757	978,956	822,643					
46 Utica Avenue	10,883,980	11,714,042	2,051,814	1,679,746					
47 Tompkins Avenue	6,135,467	6,724,211	1,129,990	948,714					
48 Lorimer Street	4,564,964	4,965,289	819,524	677,175					
49 Ocean Avenue	4,163,626	4,571,503	758,006	627,272					
52 Gates Avenue	5,436,191	6,020,400	1,044,925	877,520					

STATEN ISLAND BUS

R-1 Richmond Terrace	1,392,616	1,453,010	\$ 257,457	\$ 203,571	R-109 Midland Beach	285,406	298,881	\$ 46,316	\$ 38,789
2 Bay Street	2,161,045	2,288,846	409,764	328,568	110 Manor Road	331,889	349,484	56,907	45,435
3 Castleton Avenue	1,698,732	1,966,461	351,558	274,310	111 Bradley Avenue	639,555	570,003	96,732	70,847
4 Richmond Avenue	676,009	694,829	116,215	89,494	112 Victory Blvd.-Travis	537,130	530,360	94,010	67,753
5-101 Jersey Street-Brighton Avenue	1,066,573	1,133,919	196,910	154,856	115 Prince's Bay	91,162	68,413	9,843	5,817
6 Victory Boulevard	2,416,029	2,514,116	432,922	338,891	Miscellaneous(a)	—	(251,845)	—	—
6X Clove Road Shuttle (fr. 6/26/67)	543	—	109	—	Total	24,632,617	24,924,040	4,353,397	3,386,820
7 Verrazano-Narrows Bridge(b)	2,003,711	1,975,675	369,442	276,486	Adjustment of High School Fares	(6,363)	78,597	—	—
7A Verrazano-Narrows Bridge So. Beach Bklyn. (fr. 7/3/66)	10,602	—	2,028	—	Unregistered Elem. School Fares (on Monthly Passes)	2,821,616	2,585,221	75,855	72,137
8X Staten Island Brooklyn Express (fr. 11/3/65)	49,087	18,006	14,727	5,402	Unregistered Elem. School Fares (on Federal Grant)	21,158	—	4,854	—
102 Henderson Avenue	1,412,741	1,500,454	239,613	194,156	U. S. Post Office Fares	16,620	24,073	3,324	3,612
103 Hylan Boulevard	3,156,547	3,067,258	501,044	383,682	Add. School Revenue Payable by City of N. Y.	—	—	1,479,731	1,021,550
104 Tompkins Avenue	444,208	474,132	79,570	63,401	TOTAL STATEN ISLAND BUS	27,485,648	27,611,931	\$ 5,877,161	\$ 4,484,119
105 Clove Road (to 11/3/65)(b)	—	145,709	—	19,739					
106 Watchogue Road	708,215	742,870	122,296	96,078					
107 Forest Avenue	2,588,165	2,596,210	476,341	362,636					
1108 Richmond Rd.	—	—	—	—					
113 Arthur Kill Rd.	2,762,392	2,787,249	480,193	366,909					
117 New Detp. Lane	—	—	—	—					

(a) Represents recomputation of passenger figures for 1966 to conform with present procedure.

(b) As of November 3, 1965, the Verrazano-Narrows Bridge was extended to include operation of the Clove Road Line.

EXHIBIT

7

August, 1967

TRANSIT RECORD

7

NEW YORK CITY TRANSIT AUTHORITY—RAPID TRANSIT OPERATION

REVENUE PASSENGERS FOR TWELVE MONTHS ENDED JUNE 30, 1967 AND 1966

REVENUE PASSENGERS BY STATIONS—(Continued)

STATION	Twelve Mos. Ended June 30 1967	Twelve Mos. Ended June 30 1966	STATION	Twelve Mos. Ended June 30 1967	Twelve Mos. Ended June 30 1966	STATION	Twelve Mos. Ended June 30 1967	Twelve Mos. Ended June 30 1966
IRT LINES(a)			IRT LINES(a)—Cont.			IRT LINES(a)—Cont.		
BROADWAY 7TH AVE. LINE(a)			LEXINGTON 4TH AVE. LINE(a)			BROOKLYN LINE(a)—Cont.		
South Ferry	4,039,231	4,006,142	Bowling Green	6,638,794	6,256,396	Sutter Ave. (Rutland Road)	2,144,847	2,110,604
Rector Street	2,024,518	1,893,698	Wall Street and Broadway	8,911,634	8,279,301	Saratoga Avenue	2,095,095	2,148,497
Cortlandt Street	1,738,934	2,015,767	Canal Street	943,911	949,908	Rockaway Avenue	1,486,138	1,531,891
Wall and William Streets	8,505,731	7,990,712	Spring Street	1,696,557	1,716,924	Junius Street	823,194	943,500
Park Place and Broadway	1,067,696	1,079,751	Bleecker Street	2,074,840	2,112,952	Pennsylvania Avenue	1,641,263	1,538,181
Chambers Street	2,535,172	2,637,221	Astor Place	4,274,345	4,024,756	Van Siclen Avenue	982,518	986,135
Franklin Street	1,045,344	1,053,388	23rd Street	8,591,800	8,193,953	New Lots Avenue	1,478,657	1,403,043
Canal Street	1,517,731	1,537,813	28th Street	6,140,740	5,952,699	NORTHWARD AVENUE BRANCH		
Houston Street	3,273,773	3,176,667	33rd Street	6,896,777	6,628,404	President Street	670,390	647,481
Christopher St. Sheridan Sq.	2,828,689	2,737,658	Grand Central	40,842,646	39,457,244	Sterling Street	1,420,801	1,355,849
14th Street	6,862,905	6,926,282	51st Street	9,116,266	8,821,542	Winthrop Street	1,517,651	1,416,729
18th Street	1,946,106	1,895,933	68th St. (Hunter College)	7,537,267	7,302,090	Church Street	2,237,014	2,184,134
23rd Street	4,163,974	4,184,743	80th Street	6,678,673	6,378,211	Beverly Road	1,686,217	1,053,373
28th Street	3,472,163	3,587,099	90th Street	9,840,601	9,523,618	Newkirk Avenue	2,233,560	2,111,135
Pennsylvania Station	20,799,371	20,276,324	103rd Street	3,814,257	3,757,400	Flatbush Avenue	5,646,125	5,591,251
50th Street	7,642,467	7,540,744	107th Street	4,090,912	4,174,581			
60th Street	3,717,832	3,699,315	110th Street	3,408,016	3,472,901	Total(a)	51,935,231	53,158,686
72nd Street	6,935,054	6,953,627	116th Street	4,353,214	4,516,192	QUEENSBORO LINE(a)(b)		
79th Street	3,589,362	3,499,083	125th Street	5,367,222	5,505,817	Fifth Avenue, Manhattan	4,549,386	4,430,778
86th Street	4,432,852	4,465,995	138th St. and Grand Concourse	700,016	695,026	Vernon Blvd. & Jackson Ave.	1,670,324	1,725,257
90th Street	6,853,268	6,920,004	149th St. and Grand Concourse	1,666,526	1,688,705	49th Ave. Hunter's Pt. Ave.	3,488,074	3,377,687
103rd Street	3,598,875	3,597,977	161st Street	1,803,588	1,914,101	45th Road-Court House St.	1,696,198	1,055,594
110th St. (Cathedral Pkwy.)	3,265,936	3,248,023	167th Street	2,055,015	1,953,798	Queensboro Plaza (IRT and BMT)	2,979,065	3,015,530
116th St. (Columbia Univ.)	3,292,549	3,298,550	170th Street	2,027,792	1,937,858			
125th Street	2,162,348	2,208,260	Mt. Eden Avenue	1,352,634	1,298,793			
137th Street (City College)	3,982,638	3,955,770	176th Street	1,509,073	1,438,130			
147th Street	1,902,525	1,980,516	Burnside Ave. (N.Y.U.)	2,450,133	2,353,820			
157th Street	2,056,296	2,009,863	183rd Street	1,195,670	1,176,919			
181st Street	2,402,932	2,435,135	Fordham Road	1,901,343	1,860,645			
191st Street	1,109,439	1,582,666	Kingsbridge Road	1,547,568	1,531,970			
Dyckman Street	1,777,479	1,467,479	Bedford Park Blvd. 200th St.	826,589	778,618			
207th Street	722,004	732,008	Woodlawn Parkway	1,331,018	1,325,333			
215th Street	215,284	228,556	Woodlawn	1,467,987	1,410,165			
225th Street	921,879	944,141	Total(a)	162,793,914	158,306,172			
231st Street	1,610,389	1,629,133	PELHAM BAY PARK BRANCH					
238th Street	1,056,395	1,025,898	138th St. & Third Ave.	2,211,470	1,963,343			
242nd St. (Man. College)	1,837,003	1,874,436	Brook Avenue	2,958,920	3,306,128			
Total(a)	131,100,774	129,762,751	Cypress Avenue	1,714,183	1,784,970			
LEXINGTON AVE. & WH. Pt. Rd. Br.			East 149th Street	801,615	802,722			
110th St. & Lenox Ave.	1,974,859	2,069,379	East 149th Street	1,984,348	2,058,458			
116th St. & Lenox Ave.	2,961,039	3,121,818	Longwood Avenue	1,371,887	1,432,290			
125th St. & Lenox Ave.	3,606,481	3,725,214	Hunts Point Avenue	2,790,473	2,811,845			
135th St. & Lenox Ave.	4,237,099	4,298,959	Whitlock Avenue	733,400	749,919			
145th St. & Lenox Ave.	1,547,267	1,343,405	Elder Avenue	1,689,537	1,611,375			
149th St. and Third Ave.	6,894,742	7,148,743	Sound View Avenue	2,381,493	2,250,863			
Jackson Avenue	2,647,466	2,788,049	St. Lawrence Avenue	1,157,181	1,106,399			
Prospect Avenue	3,985,745	4,110,395	East 177th St. (Parkchester)	3,213,547	3,174,878			
Intercare Avenue	1,607,411	1,667,988	Castle Hill Avenue	1,640,615	1,621,132			
Simpson Street	3,272,964	3,415,328	Zerega Avenue	593,727	588,827			
Freeman Street	3,223,547	3,374,499	Westchester Square	1,699,027	1,624,463			
174th Street	3,518,566	3,556,802	Middletown Road	592,882	588,925			
177th Street	3,110,902	3,217,875	Bulme Avenue	1,394,143	1,348,163			
East 180th Street	1,248,071	1,268,206	Pelham Bay Park	1,391,015	1,407,349			
Roux Park East	488,979	480,507	Total	30,319,465	30,181,049			
Pelham Parkway	1,964,237	1,957,757	BROOKLYN LINE(a)					
Allerton Avenue	1,465,375	1,413,637	Clark St. (Brooklyn Hts.)	1,871,447	1,772,738			
Burke Avenue	982,528	979,132	Hast Street	2,900,263	2,826,540			
Gun Hill Road	1,167,881	1,164,124	Nepons Street	2,493,717	2,353,460			
East 219th Street	849,598	833,463	Atlantic Avenue	5,345,641	5,365,222			
East 225th Street	1,249,834	1,243,204	Bergen Street	1,075,098	1,111,918			
East 233rd Street	1,673,985	1,672,298	Grand Army Plaza	2,005,862	1,976,676			
East 240th Street	818,790	837,836	Eastern Pkwy. (Bklyn. Mtc.)	1,259,868	1,208,535			
East 241st Street	1,389,262	1,397,444	Franklin Avenue	2,535,716	2,535,716			
Total	55,087,137	56,435,992	Kingston Avenue	1,510,972	1,437,012			
			Utica Avenue	6,237,229	6,169,783			

(a) Excludes interdivisional free transfer stations; see page 8.
(b) Astoria Branch of the Queensboro Line is operated by and included under the BMT Div.

EXHIBIT 8- TURNSTILE COUNT, NEW YORK

DIVISION IRT

NEW YORK CITY TRANSIT AUTHORITY
ACCOUNTING DEPT.-PASSENGER REVENUE AUDIT SECTION

LINE LEXINGTON AVE

PASSENGER REGISTRATIONS BY HOUR - RAPID TRANSIT LINE

FOR DAY Wednesday DATE October 11, 1951

STATION AND BOOTH	HIGH TURNSTILE UNITS	12 MID. TO 1 A.M.	1 A.M. TO 2 A.M.	2 A.M. TO 3 A.M.	3 A.M. TO 4 A.M.	4 A.M. TO 5 A.M.	5 A.M. TO 6 A.M.	6 A.M. TO 7 A.M.	7 A.M. TO 8 A.M.	8 A.M. TO 9 A.M.	9 A.M. TO 10 A.M.	10 A.M. TO 11 A.M.	11 A.M. TO 12 NOON	12 NOON TO 1 P.M.	1 P.M. TO 2 P.M.	2 P.M. TO 3 P.M.	3 P.M. TO 4 P.M.	4 P.M. TO 5 P.M.	5 P.M. TO 6 P.M.	6 P.M. TO 7 P.M.	7 P.M. TO 8 P.M.	8 P.M. TO 9 P.M.	9 P.M. TO 10 P.M.	10 P.M. TO 11 P.M.	11 P.M. TO 12 MID.	TOTAL	
33RD ST																											
231		102	34	8	7	5	11	46	92	232	199	195	227	241	448	1097	669	2116	464	981	333	467	145	120	129	11956	
231A									29	155	181	112	129	124	106	300	364	1191	2857	420						5768	
232A									41	82	81	49	91	29	67	234	155	613	878	108						2228	
232		69	20	8	3	0	11	32	214	349	220	225	188	235	257	338	407	790	1740	706	250	235	154	116	71	6666	
TOTAL		171	54	16	10	5	22	78	376	838	681	581	635	629	878	1971	1593	4709	9479	2215	583	704	349	236	208	27018	
GRAND CENTRAL									9	19	69	83	115	99	111	253	198	610	1443	151						3160	
233																										248	
233H1	248																									248	
236		315	94	61	25	22	27	66	228	637	1008	695	336	782	332	904	1473	1365	4885	1606	991	495	463	338	223	17377	
237		146	69	14	18	5	9	26	63	192	237	335	312	531	324	701	1279	1442	5246	1422	449	293	378	534	130	12302	
237A									1	13	18	36	54	111	77	139	148	262	1512	1157	162	82				3772	
238		221	485	218	133	68	26	41	85	501	466	1038	1426	976	910	741	3639	4141	2308	1837	2078	1242	1174	247	651	24652	
238A										405	230							867	2632	612						47116	
238B									28	460	2815	920	81	204	307	109	293	421	544	4353	1701	457	179			13372	
240		1003	503	356	142	90	23	255	550	3259	2588	776	672	1629	1171	1644	2973	5577	8480	3501	1950	740	965	1385	1117	41350	
241									91	216	360	430	344	617	306	1076	1217	2237	6267	2158						15337	
241A		267	75	34	25	18	8	34	83	12	81	135	172	239	254	345	861	2413	8128	1826	1299	213	130	310	251	17263	
TOTAL	248	1952	1226	683	343	203	93	451	1582	8174	5995	3627	3692	5307	4156	6105	12323	20708	14919	14976	7306	3162	3110	2845	2372	155478	
51ST ST																											
242		201	105	67	39	17	22	40	128	592	712	702	578	822	874	1343	1574	2541	4623	1649	320	307	117	489	316	18178	
243		380	180	63	45	18	26	49	147	111	181	219	302	389	242	1081	1419	2040	3585	3116	1772	616	542	678	330	17581	
TOTAL		581	285	130	84	35	48	139	275	703	893	921	880	1211	1116	2424	2973	4581	8208	4765	2092	923	654	1167	646	35759	
59TH ST																											
68TH ST																											
246		216	221	116	50	18	164	781	35	2343	1506	1137	366	1820	1892	147	3388	2482	4700	3410	1885	600	2336	1098	488	31199	
77TH ST																											
247		74	21	13	5	4	3	24	137	303	120	95	100	94	108	425	477	778	802	663	325	218	187	15	124	5180	
248		171	33	27	9	14	10	126	484	1550	4245	1806	624	720	1175	966	979	1319	1481	1378	801	462	185	621	233	19419	
TOTAL		245	54	40	14	18	18	150	621	1853	4365	1901	724	814	1283	1391	1456	2097	2283	2041	1126	680	372	696	357	24599	
86TH ST																											
249		103	135	108	27	25	34	21	45	477	1499	149	171	110	230	1006	863	893	1170	781	617	119	161	603	202	8549	
250		271	198	77	29	28	33	427	1196	5485	3546	1621	621	757	730	729	2042	548	1261	555	3348	892	463	866	491	26236	
TOTAL		374	333	187	56	53	67	448	1241	5962	4045	1770	792	867	960	1735	2405	1441	2431	1336	3963	1011	624	1469	693	34785	
94TH ST																											
251		67	29	12	7	9	28	554	1488	2201	1056	256	318	561	216	509	649	1182	972	716	798	447	229	485	226	13497	
103RD ST																											
252		65	60	78	26	18	5	699	2219	2539	981	325	432	412	212	812	671	418	703	657	363	831	365	398	126	13427	
116TH ST																											
253		36	11	4	2	11	57	209	322	234	67	67	59	108	65	197	179	182	388	234	206	131	103	178	77	3127	
254		31	19	4	7	24	185	432	1881	236	354	123	118	145	67	166	265	271	223	157	130	52	76	87	42	5687	
255									296	574	392	104	83	25	38	246	69	80	78								1985
TOTAL		67	30	8	4	35	242	631	2499	1644	813	294	260	278	172	609	513	533	689	397	336	183	179	265	119	10799	

APPENDIX II

An Example of a Schedule and a Set of Runs

A portion of the schedule and work program (run sched.) for the East 180th-Dyre Avenue Lexington subway service in New York is shown in Exhibits 9 and 10. Note that in the schedule trains may run express from 241st Street, local from Dyre Avenue or local from East 180th Street in the Bronx; and that trains from these three points may go to Utica Avenue, South Ferry or Atlantic Avenue (or, on other pages, New Lots Avenue).

The peak load points on this line are, from the Bronx, at 59th Street (between 125th and Grand Central), and from Brooklyn, at Bowling Green. "P" indicates a train being put into service from storage in a yard, tunnel or middle track; "L" indicates a train being taken out of service into storage (or maintenance). All trains operating in the hours shown are ten cars.

The scheduled running time is read as, for example, 69 to 71 minutes from Dyre Avenue to Utica Avenue, or as 8 minutes from Grand Central to Brooklyn Bridge. The terminal layover time at Utica Avenue for the first train listed is ten minutes. These first several trains, in actual practice, do not usually leave Utica on time; delays enroute southbound are generally greater than the ten minutes allowed in layover. Conversely, the actual running time for the trains shown at the bottom of the page is 5 or 6 minutes faster than that shown on the schedule.

EXHIBIT 9

IRT DIV. FILE NO. 3- 1697
DAILY TRAIN SCHEDULE
IN EFFECT:

NEW YORK CITY TRANSIT AUTHORITY

SHEET NO. 2-OF 6
SUPER. FILE NO. 3- 1506
(4-19-65)

180TH ST. - DYRE AVE. - LINE

241ST LEAVE EXP	DYRE ARRIVE	AVE LEAVE	EAST ARRIVE	180TH ST LEAVE	149TH ST LEAVE	125TH ST ARRIVE	G.CEN LEAVE	B.B. LEAVE	B.GRN LEAVE	SOUTH-FERRY ARRIVE	A.A. LEAVE	FKLIN LEAVE	UTICA AVE. ARRIVE	FRANKLIN. ARRIVE	A.A. LEAVE	B.GRN LEAVE	B.B. LEAVE	G.CEN LEAVE	125TH LEAVE	149TH ST LEAVE	180TH ST ARRIVE	DYRE ARRIVE	238TH ARRIVE
				LOC	EXP														LOC	EXP			
P-710X			P- 717	717	732	738	749	757	801		809	813	816	826x	829	833	842	846	854	904	910	921	LIGHT 932 1/2 L
				725	736	742	753	801	805		813	817	820	830	833	837	846	850	858	908	914	928	939
	P 711	722	723		738	744	755	803	807		815	819	822	833	836	837	841	850	854	902	912	918	932 L
			P- 727	742	748	759	807	811			819	823	826	836x	839	843	852	856	904	914	920	931	LIGHT 942 1/2 L
P-719X				734 1/2	745 1/2	751 1/2	752	803	811	815	823	827	830	840	843	847	856	900	908	918	924	938	
	709	721		732	747	753	754	805	813	817	825	829	832	845	848	852	901	905	913	923	929	943	954
			P- 736	751	757	758	809	817	821		829	833	836	851	854	858	907	911	919	929	935	949 L	
P-729X				744	755	801	801 1/2	813	821	825	833	837	840	856	859	903	912	916	924	934	940	954	
										902	913					914	918	926	936	942	956 L		
	721	731		742	757	803	803 1/2	815	823	827	835	839	842 L										
			P- 749 1/2	800 1/2	806 1/2	807	819	827	831		839	843	846	903	906	910	919	923	931	941	947	1001	1012
	P	735	746	747	802	808	809	821	829	833	841	845	848 L										
P-740X				755	806	812	812 1/2	824 1/2	832 1/2	837	845	849	852	911	914	918	927	931	939	949	955	1009 L	
	733	742		753	808	814	814 1/2	826 1/2	834 1/2	839	847	851	854 L										
										912	928												
			P	757	812	818	830	838	843		851	855	858 L										
P-750X				805	816	822	834	842	847		855	859	902	919	922	926	934	938	946	956	1002	1016	1027 L
	744	752		803	818	824	836	844	849		857	901	904 L										
P-756X				811	822	828	840	848	853		901	905	908	927	930	934	942	946	954	1004	1010	1024 L	
	754	800		811	826	832	844	852	857		905	909	912 L										
			P	815	830	836	848	856	901	902													
P-806X				821	832	838	850	858	903		911	915	918	935	938	942	950	954	1002	1012	1018	1032	1043
	803	811		822	837	843	854	902	907		915	919	922 L										
P-815X			830	831	842	848	859	907	911	912													
	811	818		829	844	850	901	909	913		921	925	928	943	946	950	958	1002	1010	1020	1026	1040	
	819	824		835	850	856	906	914	918		926	930	933	951	954	958	1006	1010	1018	1028	1034	1048	1059
	825	832		843	858	904	914	922	926		934	938	941	1001	1004	1008	1016	1020	1028	1038	1044	1058	
	831	839	850	851	906	912	922	930	934		942	946	949	1011	1014	1018	1026	1030	1038	1048	1054	1108	1119
	837	848	859	900	914	920	930	938	942		950	954	957	1024	1024	1028	1036	1040	1048	1058	1104	1118	
	849	856	907	908	922	928	938	946	950		958	LT 1005	1005 L										
	855	907		918	932	938	948	956	1000		1008	LT 1012	1012 L										
			913	928	942	948	958	1006	1010		1018	LT 1022	1022 L										
	920	927		938	952	958	1008	1016	1020		1028				1038	1046	1050	1058	1108	1114	1128	1139	
			938	948	1002	1008	1018	1026	1030		1038				1048	1056	1100	1108	1118	1124	1138	1150	
	939	947		958	1012	1018	1028	1036	1040		1048				1058	1106	1110	1118	1128	1136	1150	1159	

EXHIBIT 10

IRT DIVISION - FILE NO 3 - 1697 A
NOTORIEN & CONDUCTORS 1ST
DAILY WORK PROGRAM - IN EFFECT:

NEW YORK CITY TRANSIT AUTHORITY
180ST - DYRE - LEXINGTON AVE LINE

SHEET NO 2 OF 5
SUPERSEDING FILE NO 3 - 1586 A
(4/19/65)

NAME	PASS NO	DAYS OFF	RUN NO	REPORT		LEAVE	DYRE AVENUE		ATLANTIC AV		UTICA AVENUE		DYRE AVENUE		180TH ST		ATLANTIC AV		DYRE AVENUE		180TH	RELIEVED		TIME				T I H E	DIFF
				TIME	PLACE		ARRIVE	LEAVE	ARRIVE	LEAVE	ARRIVE	LEAVE	ARRIVE	LEAVE	ARRIVE	LEAVE	ARRIVE	LEAVE	ARRIVE	LEAVE		TIME	PLACE	ACT'L	O'ALL	ALL'D			
			17	615	180TH	625					722	739	849	856	(907	1048)	1138	1208			1258	103	180TH	648		8			
			18	630	241ST	640x					750	804			(903	1058)	1148	1228			118	123	180TH	653		8			
			19	621	180TH	631					728	745	855	907	(918	1108)	1158	1248			138	143	180TH	722		8			
			20	624	180TH	634N	645	702			812	826x			921	LITE TO 238ST - DEADHEAD													
			21	624	180TH	634N*		652			802	816x			(1000	1118)	1208	108			158	203	180TH	739		8			
			22	1148	AT.AV				1158				1259	107	(950	1128)	1218	128			218	223	180TH	759		8			
			23	1158	AT.AV				1218				119	127	138	545)			424 (N'LTS) 652	431	(442)	657	N'LTS	709		8	1:48		
			24	1159	180TH	1218			108	118			219	236	(247	433)			555)	440 (N'LTS) 702	(458)	707	N'LTS	709		8	1:58		
			25	717	UTICA						532	552	702	711	722	(FKLIN)					727	180TH	728		8	1:59			
			26	305	AT.AV				315				416	422	433	458					(UTICA) 557	1027	FKLIN						
			27	745	UTICA				RELAY IN		755	906*			938	958	1048				(N'LTS) 601	1053	AT.AV	607	1045	845	:02		
			28	257	AT.AV				307				408	414	425	453					606	606	N'LTS	617	1021	830	:15		
			29	637	180TH	647					746	801	912	927	938							943	180TH						
			30	118	180TH	128			218	238			339	350	401							406	180TH	554	929	8			
			31	647	180TH	657					756	810	920*		958							1003	180TH						
			32	128	180TH	138			228	DEADHEAD		351			450							455	180TH	643	1008	808			
			33	657	180TH	707					806	820	929	947	958							1003	180TH						
			34	138	180TH	148			238	331			432	440	451							456	180TH	624	959	8			
			35	700	180TH	710N*	731				842	LITE TO NEW LOTS				(N'LTS)						856	N'LTS			806			
			36	118	180TH	128N*	206	307	DEADHEAD							352					501	506	180TH	544	1006	806			
			37	707	180TH	717					816	830	939*		958							1003	180TH						
			38	158	180TH	208			258	DEADHEAD		339	448	457	508							513	180TH	611	1006	806			
			39	713	180TH	723					822	836x			931	LITE TO 238TH ST						947	238TH						
			40	335	UTICA						345	456	506	517								522	180TH	421	1009	809			

NOTE: (*) INDICATES CREW WILL OPERATE TRAIN TO OR FROM E. 180ST "IF ORDERED TO DO SO".

The excerpted page from the work program gives an idea of how complex run-splitting can be. Note that lay-over times for the crews are longer than for the trains. Thus the first train on the schedule, the 7:17 A.M. from East 180th to Utica is due to leave Utica at 8:26, but its crew, run 31, take the follower, the 8:30 from Utica, while the crew that has picked run 20 take the train out at 8:26. Of course if run 31 arrives with their train at, for example, 8:30, 14 minutes late, the crew with run 20 must wait for them and leave late (nor will run 31 make an 8:30 out, it might be added).

Note that runs 17 through 24 are straight runs, runs 25 through 32 are swing. Lunch hours for the straight runs are the times in parentheses, and vary from 57 to 115 minutes (the contract minimum is 35). Actual time worked in the column at the right includes lunch relief and terminal layover time; note in spite of this how much less than eight hour's work is required of each employee for the eight hour's pay. Overall time is the spread time; notice that for a spread of less than ten hours, no penalty is paid, while for a spread of ten to eleven hours, full time is paid for the excess above ten hours. Differential is the number of hours and minutes worked from 6:00 P.M. to 6:00 A.M. (for which a bonus of a few cents is paid), computed on an eight hour basis from report time, not on the actual relief time.

CHAPTER III

SYSTEMS ANALYSIS AND TRANSIT SCHEDULING

CHAPTER III

Systems Analysis and Transit Scheduling

Schedule and Route Planning in urban mass transit are presently non-programmed activities, not in the sense of being a new problem, but as described in the previous chapter, in the sense of being undefined, disorganized and solved by judgment. Albeit parts of the process^{are} organized; some systems - notably Cleveland - are more systematic in their scheduling procedures than others. There is no absolute dividing line between systems analysis and present scheduling methods, but it will become clear as we define systems analysis and look at the way each step is handled that the opening statement is justified.

Systems analysis has not been introduced into the scheduling process; indeed, there are few people in the industry who are aware of its relevance. This is because the manner and forum of discussion of the whole field of systems analysis, operations research and management science have been alien to urban transit management's test of relevance: what is useful. In most professional journal articles, for example, "the attitude is that of an exercise in formal logic rather than that of a search for useful solutions of real problems."¹ Further, there is a preoccupation with "optimum" solutions, although for most management problems, "mathematical methods fall far short of being able to find the 'best' solutions. The misleading objective of trying only for an optimum solution often results in simplifying the problem

until it is devoid of practical interest."² (See Chapter 2, pages 60 ff.)

There is, according to Forrester in the above quoted test, a dichotomy between practicing management and the scientists and engineers working in this area. He represents two regions, diagrammatically, and in a series of scathing comments, suggests for example that in one, "the goal is improvement of real situations;" in the other, "the explicit or the optimum solution to unrealistically simplified hypotheses." The manager "acts on such information as he can obtain;" "the analyst often ignores phenomena that he admits are crucial but that cannot be precisely measured."³ The analyst usually ignores nonlinear behavior, loses the nature of individual action by extracting from averages and aggregates, and so on. While somewhat exaggerated, the fact is that:

"The 'art' of Region A (management) is still better able to deal with decisions of great consequence than the 'science' of Region B (analyst). The overlap between the two is slight. The manager has often found that management science did not deal with his most urgent problems. It has not learned to take into account the variables that he knows to be important. It is not cast in a language with which he is familiar."⁴

It is the intent of this thesis to overcome some of this for the urban transit industry. Emphasis will accordingly be on what is relevant and meaningful to transit management. The methods proposed and techniques used may not always be mathematically or econometrically precise and acceptable, but it is hoped that they will generally be appropriate to the issues and data at hand.

Systems Analysis: Definition

Decision making can be viewed as dealing with two types of problems: programmed and non-programmed.

Programmed problems are ones which an organization has repeatedly had to solve, and for which routine procedures have been developed. Objectives and operating procedures are well defined through habit and experience.

Non-programmed problems are in some sense unplanned; there is no well defined method of solution. If one asks a planner how he arrived at a solution for such a problem, he will say he "exercised 'judgement', and that this judgment depends, in some undefined way, upon experience, insight, and intuition."⁵

The distinction, of course, is not in reality a dichotomous one. In particular, a non-programmed problem may be one with which an organization has been dealing for some time but which is still solved by judgement. While the objectives and procedures may be routine, they will also be undefined and disorganized.

This does not mean that non-programmed decision making cannot be successful a good deal of the time. "Any worthwhile human endeavor emerges first as an art. We succeed before we understand why."⁶ Non-programmed decision-making is an art, developed through empirical experience.

But

"Without an underlying science, advancement of an art eventually reaches a plateau." It "in time ceases to grow because of the disorganized state of its knowledge. . . . If progress is to continue, an applied science must (be developed) to explain, organize, and distill experience into a more compact and usable

Systems analysis is a method which addresses itself to putting the relevant factors of such problems into order. Arthur Hall, a systems expert at Bell Labs, defines a "system" as any set of objects with relationships between the objects and between their attributes; and to the environment in which it functions.⁸ The environment should ideally include all things affecting the system, but in practice must usually be limited to those things which have a significant effect on the system. Analysis of the system and its environment enables one to see all the isolated segments as tied together by interdependent functions.

Systems Analysis can thus be understood as a "set of techniques. . . that enables one to see isolated objects, or a piecemeal series of events, as interconnected and mutually dependent."⁹ In this context it becomes easier and more desirable to generate and evaluate alternative solutions to a problem by manipulating the objects and events in their interrelationships. Although this can be done by hand, or with a slide rule and calculator, the increasing size, speed and availability of computers make it possible to evaluate many more alternatives. The planner-analyst

"not only can evaluate, but can now also define alternatives much more precisely with much more data than he could use before. He can process the information in many ways and compare the systems outputs from a variety of viewpoints."¹⁰

The use of the computer does not, however define systems analysis any more than any other tool that may be

employed as a means to the method. Systems analysis is properly defined by a series of steps, all of which are essential to the method.

Steps in Systems Analysis

1. Problem definition, including the identification of the purpose, objectives and output of the system. Because of the difficulty of agreement, planning objectives are often implicit or rest on weak foundations and unproven assumptions. The entire procedure of systems analysis, however, rests upon a quantitative evaluation of the stated objectives, and therefore requires explicit objectives to measure. In requiring precise description of major objectives, a common ground can often be provided for cooperation among departments, organizations and even political groups. This aspect has "all by itself brought about major changes in the Defense Department and has been one of Secretary McNamara's prime tools to effect change in out-dated procedures."^{11a}

"The really difficult and important part of doing a good analysis is not the computation; it is formulating and defining the problem, clarifying the objectives, and determining which assumptions ought to be considered."^{11b}

For this reason, systems analysis is not the exclusive domain of computer experts and mathematicians. It is more generally, but not necessarily, the product of an interdisciplinary team or background.

2. Definition of operational measures. Quantitative measures must be determined for all aspects of the system in order to evaluate whether and how well the solution

satisfies the objectives defined in the first step. Where no data exists, experience and research should be employed. Of course, no planner, engineer, designer or analyst can quantify, or for that matter, predict, the relative importance that decision-makers will in practice ascribe to all the factors to be considered. It is important, however, to quantify as many aspects as possible, or at least to determine the value of one objective as a substitute for another. As McNamara points out,

"To undermanage reality is not to keep it free. It is simply to let some force other than reason shape reality. That force may be unbridled emotion; it may be greed; it may be aggressiveness; it may be inertia; it may be anything other than reason. To argue that some phenomena transcend precise measurement - which is true enough - is no excuse for neglecting the arduous task of carefully analyzing what can be measured." 12

Systems analysis is a rational process, and only operational (=testable = measurable) goals lead towards rational analysis; non-operational goals lead to bargaining and dispute.¹³ It is important to note that an operational goal does not necessarily have to have a number attached to it; the qualities which make it operational are that it is explicit, consistent, and testable. One of the contributions of systems analysis is that a goal such as an aesthetically attractive right of way can be included as an objective, even if there is no precise worth that can be placed on it in economic terms. There is, of course, no all inclusive "magic answer" arising out of systems analysis.

One must

"Render unto the computer those things that are the computer's and to judgement the things that are judgement's. In the end, there is no question that analysis is but an aid to judgement and that, as in the case of God and Caesar, judgement is supreme." ¹⁴

In this light, the most appropriate function of the systems analyst is "to present decision-makers with an interesting set of alternatives together with an explicit identification of their consequences rather than a single solution" ¹⁵ and to indicate what may happen if his (the analyst's) assumptions are incorrect. This jumps us several steps ahead, however; further consideration of the process of evaluation and selection will be given in steps 5 and 6.

3. Model definition. In quantifying relevant aspects of the system, one must at the same time perceive the way in which these aspects are functionally related with each-other and with the environment.

A model is simply a collection of equations and relationships which describe the system. It is a mathematical or symbolic representation of the facts and of the system's behavior. It need not consist entirely of formulas or equations, as the exact relations between variables are often not clear to the analyst. In forming a model of the system, the basic steps can be described as:

- a) Separate the system into its component parts
- b) Form theories to explain how the component parts interact with each other and with the environment

c) Check to see if the theory explains the known facts and observations for each postulated relationship (this involves reformulating the facts in terms of the theories)

d) Test the validity of the theorized interactions (represented by equations, or statements, or ratios, or some other symbolic representation) through prediction.

The above process, which is a variant of the "scientific method", will make clearer what parts of the system can be manipulated and what the results of varying the subsystem characteristics will be. From the first it then becomes possible to

4. Generate alternatives. Knowing which parts of the system can be varied, to effect a change in a given objective in the intended direction establishes a precise correspondence between the alternatives proposed and the results desired, in a way that would not be possible without systems analysis. It may reveal several alternate ways of achieving an objective, where only one was thought possible. And the previous steps make it possible to use computers to generate a more extensive range of alternatives than could be done by hand, where this is possible.

From the second (perceiving the results of manipulating subsystem variables) it is possible to

5. Evaluate alternatives, in terms of the operational measures defined in step two. In theory one is looking for an "optimum" or best over-all system. Often, however, the real output is one or more "satisficing" solutions, which are better than the present solutions, but which may none

of them be an optimum solution - simply because the operational measures and/or the model cannot be made precise enough to predict an optimum with certainty.

In generating and evaluating alternatives, another basic aspect of systems analysis is its ability to address itself to the bulk of the problems that face the planner and decision maker which are incremental, or which should be even if they are not on the surface. The computer can search out numerous possible incremental alternatives, either by its capability of generating random selections, or through programmed criteria; the same process, to a more limited extent, can be done by hand.

"It is this process of gradual improvement by testing the effect of small changes that gives the method its resemblance to Darwin's doctrine of natural selection, the survival of the fittest."¹⁶

Directly related to this facet of systems analysis is the technique of Marginal Analysis. Marginal analysis asks what a proposed change will add to the net benefits (or costs) of a pre-defined group or groups. In urban transportation either the transit operator or the urban populace may be the groups whose benefits are weighed. Marginal decision making, according to Baumol, states "that an action merits performance if and only if, as a result, the actor can expect to be better off than he was before."¹⁷ The application of systems analysis in the generation and evaluation of alternatives will thus guarantee that economic decisions will be made on the basis of added costs and benefits, not average costs.¹⁸

6. Selection. The various alternatives are not apt to meet all the objectives equally well; in fact, none may give the precise result desired. It is here that judgment will enter the picture more explicitly than elsewhere in systems analysis. The planner should, as suggested earlier, present several alternatives to the decision-makers rather than a single solution. This is the practice that was followed in the Defense Department. 19

In selecting among several alternatives, it is often helpful to know how unplanned changes in the environment will affect the desirability of the choice made. This practice is known as Sensitivity Analysis. It "consists of varying characteristics of a system by relatively small amounts to see what effect these changes have upon other characteristics (such as cost, or output) of the system. 20

This provides a means of accounting for the uncertainties that exist in any system. For example, if analysis indicates that a 10% increase in demand on a transit line will not be accommodated by the planned capacity, then it would be desirable to increase the capacity to provide for such an increase (which might very well occur), while another line with excess capacity might not need such an increase.

7. Implementation. While not strictly a part of the method of systems analysis, the proper implementation of the chosen alternative is essential to both achievement of the objectives as envisioned in the plan and to the generation of feedback into the model (discussed below). The usual case is that different people and different approaches

are involved in the execution of a solution. As a consequence, decisions made during the program elaboration (steps one through six) are rarely re-examined during the program execution.²¹ This dilutes the effect of the whole procedure of systems analysis, and may put holes in future use of the model. For this reason, there should be ample communication between the planners and the executors of a given program.

8. Feedback. The results of implementing a given solution provide information with which the various hypotheses and functional relationships comprising the model of the system can be tested and, if necessary, changed to better represent the current state of the system. Thus a continuing feedback of such information is necessary to the successful continuance of systems analysis. Where such feedback is "real-time" or close to it, and the continuing changes in pieces of data are fed into continual computerized evaluation of incremental alternatives (sensitivity analysis),²² an information feedback-control system is in operation. An effective continuing process of systems analysis incorporates information feedback-control.

Management Organization for Systems Analysis

Systems analysis does not take place in a vacuum, of course. It takes place within an organization, and requires an organizational structure conducive to its use. For one, resources should be separately and specially allocated to the planning task; where daily routine precludes a clear understanding of the goals or an attention to inno-

Most importantly, management ought not to be too heavy, too centralized. The planner should be given encouragement and latitude to innovate, in an open-minded atmosphere, with the understanding that the alternatives presented to the decision makers will be respected and not arbitrarily discarded. Centralized control of management tends to militate against this kind of atmosphere, because of some or all of the following characteristics:²⁴

- 1) Suppression of alternatives, as lower levels of management lose their bargaining power
- 2) Dominance of a favored group in decision making
- 3) Departments or agencies lose incentive to invent
- 4) Sense of preference of superiors dampens the enthusiasm of lower levels for making strong cases for alternatives frowned upon higher up
- 5) One-shot instead of properly sequential decisions as a result of staff shortage or from resistance to too much change
- 6) Neglect of all impacts or uncertainties - only the viewpoints of the controlling group are considered
- 7) Conservative bias to choices: it is difficult to show benefits, easy to see costs.
- 8) Disregard of uncertainties, preference for "safe" proposals, little exploration of "bold" ideas.

For really effective use of systems analysis, then, a considerable amount of decisionmaking authority should be left in the hands of middle management, and the analysis and implementation should be carried through at this level, preferably under the aegis of a single person or group. This

would help integrate program solution and execution, and overcome some of the problems of centralized management outlined above, in particular one through four.

Application of Systems Analysis to Schedule and Route Planning

The first problem in applying systems analysis to schedule and route planning will be the definition of the purpose, objectives, and desired output of scheduling and route planning. As was described in the previous chapter, the purpose of a schedule from management's viewpoint is not even always the best that management could ask from it, and frequently not what the public and employees use as a test of effectiveness. Objectives, where they are defined, are not consistently adhered to; and often they are not made clear at all. The full range of possible objectives is rarely considered. Systems analysis permits the exploration of the consequences of seeking to fulfill alternate objectives; this is an advantage which the transit industry should make use of.

What, for example, would be the result of having as an objective a seats-for-all pattern in New York in the non-rush hours, rather than an average 115 to 150% load factor policy. It would cost more, of course; but how much more and in relation to what additional revenues and benefits to the community? The answers to such questions will not always be what many might intuitively expect, although some times they undoubtedly will be. Or what if a totally different objective were adopted, such as reducing

the need for additional expressway construction.

Pinning down and making explicit the objectives of a transit system's scheduling policy will, if nothing else, tend to make the adherence to these objectives more consistent - if they are accepted as continuous tests of schedule policy.

The heart of the application of systems analysis to transit scheduling and route planning will be the development not so much of the overall model, which will be presented more for a conceptual foundation than for actual implementation, but of the submodels, which will both define the relationship of the variables that can be manipulated to the environment and at the same time provide operational measures for these variables.

For example, one of the variables that can be manipulated in the schedule is headway, the interval between vehicles or trains. At present, as should be clear from the previous chapter, the only relationships and measures that are considered are those of cost to the transit system, and at that these costs are inexactly measured in many cases.

Changing the headway, however, will have a number of effects; it is important that management be aware of these effects, so as not to make decisions inimical to their own stated objectives.

Thus we will need to define the effect of changes in headways on demand, and hence revenue. A hypothesis will be presented, tested, and used; the effect will be quantified. At the same time, headway changes will mean a longer or shorter travel time for the passenger. Even if transit management places no value on this, the traveler does; and

it might be useful to attach an operational measure, such as the imputed value of time to the traveler, depending on his income and trip purpose, to compare the reduction in cost with the increase in travel times aggregated over the community.

Take, for example, a bus line with revenue per mile below some acceptable value. At present, there is not always likely to be an acceptable minimum value; systems analysis would require that one be defined, if revenue per mile is to be an objective, as an operational measure. If there is an accepted minimum, it may not be consistently applied due to political pressures or the current financial crisis; that is, no attention may be paid to lines below the minimum value unless it is necessary to cut costs (although the resources being wasted in a time of profit might better be used on some other service). An effective systems analysis applied continuously to the system would keep turning such cases up and call for changes. When changes are made at present, consistently or not, they are apt to be made without full awareness of what the effects on costs, revenues, non-transit transportation expenditures for the community, and so on will be; by plugging in alternative changes into the model, the systems analyst can show management what all these effects will be, and in a way that he can measure them against his objectives.

Importantly, in defining the relationships between variables and the environment of the transit system, it will be possible to look at the system in reverse. That is, rather

than or in addition to seeing how changes in headway may increase revenue per mile, it will be easier to see what other solutions might also do so - for example, running some buses down an alternate street, or increasing promotional efforts.

Having thus defined clear objectives, developed operational measures to test these objectives, and seen more clearly how the various components of transit scheduling interact with each other (including, for example, the effects of schedules on work programs or run splitting and vice-versa) and with their environment, we are in a much better position to generate and evaluate alternatives in the incremental manner of marginal analysis described earlier. This is so because the understanding of the interactions between variables makes it easier to see readily the many ways that a given factor can be changed, rather than only the most apparent; and the definition and quantification of objectives makes it possible to assign a measure or number to each small alternative possible change.

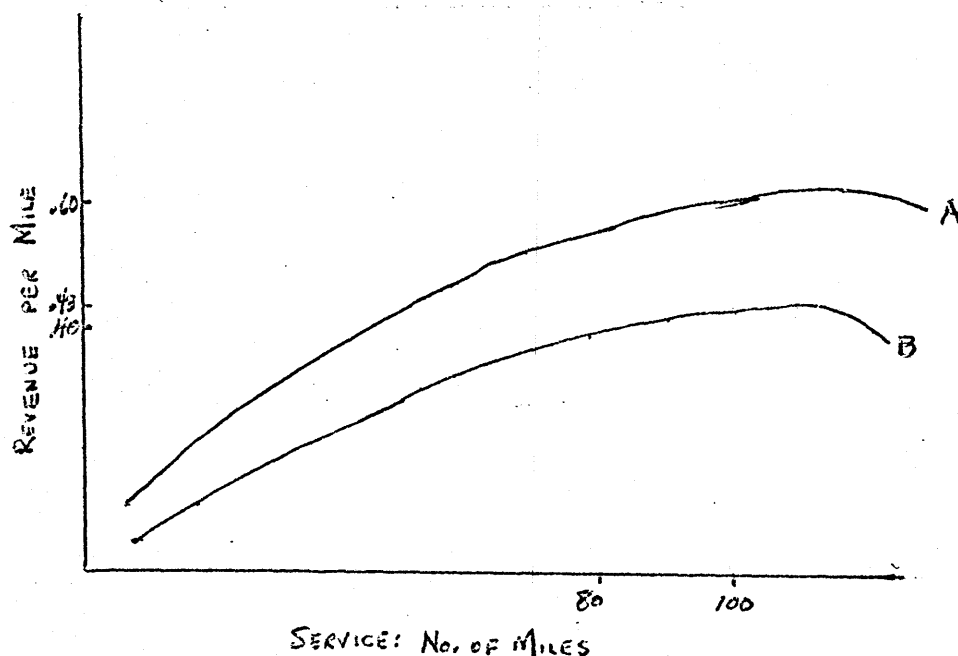
The use of average measures, so prevalent in the transit industry (and not likely to be diminished outside the framework of systems analysis) can often violate the principle of marginal decision making, however. As an example of how this occurs, let us pursue the above example, with revenue per mile as the objective.

Use of Marginal Analysis in Transit Scheduling

Consider a hypothetical pair of bus lines with returns of 60¢ and 43¢ per bus mile respectively. A not uncommon approach in urban transit scheduling is to reduce the mileage (i.e., service) on the lower-return route. However, it is entirely possible that the higher return of the former is due to service being better adapted to the market - that is, serving a greater number of potential origin-destination trip pairs at low total trip price (see chapter 6). The reduction in service in the latter may have little or no effect on its return; it may even re-
duce the return per bus mile (see Pollock's quote on p. 54, previous chapter). An analysis of the return per bus mile added or subtracted, rather than of the average returns per (existing) bus mile would have revealed this and prevented such a mistake.

Figure 1 illustrates such a case. Note that line A, which at 100 miles is making 60¢ per mile, consistently makes more revenue per mile than does line B; and that a reduction in service on either line at that point will reduce revenue per mile; in fact, the graph shows that an increase in mileage will actually increase revenue per mile. This is not an imaginary situation: chapter 7 gives several examples of such a relationship, using the hypotheses on frequency of service and through service developed in chapter five. Note that in the graph, a reduction to 80 miles brings revenue down to 40¢ per mile on line B. This is equivalent to a loss of $50\frac{1}{2}$ ¢ per mile for the 20 miles eliminated.

FIGURE 1 : REVENUE PER MILE vs. SERVICE



There are other possibilities too. The line with a lower return per bus mile may be operating on less congested streets, in less densely populated areas, and thus by virtue of its higher speed have a lower operating cost per mile which would not show up under average cost analysis; it is conceivable that the difference might be sufficient to suggest that the route with the higher return per mile is losing more money!

"The use of average data in any optimization problem can lead to such unsatisfactory results. The logic of the difficulty is not hard to explain - the question is not whether money already spent in publicizing product A has brought high returns. What must be determined is whether the spending of additional money can be justified. It may well be that the public is already saturated with product A . . . the money may be better spent on the promotion of some product B, on which previous outlays were so niggardly as to be almost completely ineffective, but where the payoff to additional expenditures may be large because they permit some sort of public perception threshold to be reached."25

Why, then, do rule-of-thumb calculations, made in terms of average rather than marginal quantities, so often serve as substitutes for optimality or satisficing computations in scheduling and route planning, and in many other business operations? The most likely answer is that it is harder to obtain marginal figures than to acquire average data, for several reasons:

1. Accounting information is usually in the form of average or total, rather than marginal, figures;
2. Marginal data may frequently require information beyond the range of the firm's actual experience;
3. When relevant data are available from past experience, it is still much easier to use the statistics required for average figures, as they require a smaller number of observations, due to existing compilations.

These reasons are all true of the transit industry. To them can be added the fact that in most transit systems, the personnel charged with determining the effects of changes in schedules and routes - usually the schedule and budget departments - are too occupied with the procedures considered

essential to the bureaucracy, largely rote or mechanical in nature, to find even a fraction of the time necessary to collect and analyze the necessary data. This refers to the whole problem of an organizational environment conducive to the introduction and thriving of systems analysis, discussed earlier in this chapter. Transit systems in general do not present such an environment, and changes along the lines suggested earlier would be necessary to make any attempt at the methods outlined here successful.

If the model of the scheduling process is accurate, the search for alternatives and the use of sensitivity analysis in their evaluation and selection will also be able to measure the effects of random and non-random variations in passenger arrival rates and vehicle arrival rates on load factors and running times, as discussed in the previous chapter. That is, the model will show that although an increment in service may reduce the average load factor to the desired objective level, a definable percentage of passengers will experience load factors above this level (with further consequences on passenger demand, running time, and so on). This is a case where evaluating the alternatives via the model may suggest the possibility of alternate objectives which management may want to satisfy. That is, in this case instead of making a load factor of 150% the objective, it may be preferable to stipulate that no

more than five percent of the passengers should experience a higher load factor.

In summary, this chapter has attempted to describe systems analysis and to show, with reference to the previous chapter describing the scheduling process now in use in the transit industry, how the essential features of systems analysis address themselves to the various shortcomings of schedule and route planning detailed previously. Succeeding chapters will attempt to develop models and procedures which will successfully fuse the two disciplines and create a method of scheduling that can readily be adopted by urban mass transit management.

Footnotes

1. Jay W. Forrester, Industrial Dynamics (Massachusetts Institute of Technology Press: Cambridge, Mass.)p. 3.
2. Forrester, ibid.
3. Forrester, p.4.
4. ibid.
5. Herbert A. Simon, The Shape of Automation for Men and Management (New York, 1965) quoted in "A Framework for Problem Solving", M.I.T. course notes by Prof. Richard L. De Neufville.
6. Forrester, p.1.
7. ibid., p.1,2,3.
8. Arthur Hall, "A Methodology for Systems Engineering", in "Performance Design", Progressive Architecture (August, 1967) 106.
9. ibid.
10. Richard L. de Neufville, "Toward a Comprehensive Systems Analysis for Transportation Planning: an Urban Example", (Department of Civil Engineering, M.I.T., Professional paper P67-7, June 1967) p. 7.
- 11a. de Neufville, "A Framework.." op.cit.(note 5), p. 6.
- 11b. Dr. Alain C. Enthoven, Deputy Assistant Secretary for Systems Analysis, Comptroller's office, Department of Defense, quoted in Prog. Arch. op.cit. p. 123.
12. Robert McNamara, United States Secretary of Defense, 1961-68, quoted in Prog. Arch. p. 123.
13. J.G. March and H.A. Simon, Organizations (New York, 1958).
14. Enthoven in Prog. Arch. p. 124.
15. de Neufville, "Toward.." op.cit. (note 6) p. 3.
16. Prog. Arch. p. 111.
17. William J. Baumol, Economic Theory and Operations Analysis (New Jersey, 1965) p. 21.

18. See the section on Marginal NOC in Chapter 4 for a mathematical representation and discussion of global vs. local optimums in marginal analysis.
19. de Neufville, "A Framework..." p. 7.
20. ibid. p. 8.
21. March and Simon, op. cit.
22. Forrester, op.cit. (note 2), refer to p. 14ff. for a discussion of feedback-control.
23. March and Simon.
24. David Novick, ed., Program Budgeting, Program Analysis and the Federal Budget (Harvard University Press: Cambridge, Mass. 1965) p. 303.
25. Baumol, op. cit. (note 17) p. 35.
26. see Baumol p. 34.

CHAPTER IV

A MODEL FOR MASS TRANSIT SCHEDULING AND ROUTE PLANNING

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④

CHAPTER IV

Introduction

In the preceding chapter, it was seen that an essential and first step of applying systems analysis to schedule and route planning is the definition of objectives, of operational measures relative to the environment and to the variable elements of schedules and routes controlling these objectives, and the interrelationships of the objectives and variables to each other.

This chapter develops a model of mass transit scheduling and route planning which makes the identification of these relationships possible. In Part I the schedules and routes are defined in terms of a series of state-of-the-system variables; their relationship to the environment (Fixed and External elements) and to the schedule and route variables controlling them (Control variables) described; and operational measures suggested for the State variables.

Part II outlines the way in which alternative objectives can be evaluated and manipulated within the framework of marginal analysis of changes in schedules and routes. The objectives are seen as a system of constraints and specifications on the operating measures of the State variables defined in Part I.

10

Specific objectives for each State variable and examples of the application of the model with respect to each State variable are the subject of a later chapter (chapter 7). This was done in order to first develop hypotheses and present data on the effects of changes in Control and State variables on revenues (chapter 5) and cost (chapter 6).

Objectives of Model

The primary function of the model is to make explicit the systematic manipulation of the state of the transportation system by changes in each Control variable, or element, of the schedule and route, in order to produce a new State, or output, closer to the desired measure of efficiency for each State variable. The model will:

1. Show the management all the points where a particular deficiency exists (subject to its objectives with regard to each State variable) by generating information on all measures of efficiency for all route segments, homogeneous time periods, etc.
2. Tell the company how alternative changes in the variables controlling schedules and routes will affect variables describing the state of the system (and thus, to the extent that the company has researched the relationships, how each change will affect costs and revenue).

3. Locate local configurations of schedule and route variables which optimize the stipulated measure(s) of efficiency (and, in theory, "global" configurations, that is, configurations over the whole system, of the control variables which improve or maximize the measures(s) of efficiency).

In economic terms, the overall objective can be said to be maximizing the supply subject to varying demand, the latter being partially influenced by the supply. The extent of the postulated influence will depend on the available functional relationships describing the effects of control variable changes on demand, which is one of the State variables (see ensuing descriptions of variables and chapter 5). The changes will be primarily short range and marginal, involving changes in modal split rather than in total travel demand or patterns (although possible changes in this area - "induced" demand, for example - cannot be ignored). Hence overall movement patterns are considered as fixed elements in the input.

The objectives of the model will require:

I. Transformation of System State by Control Variables

1. Knowing the input variables, both controlled within and external to the company, to the system state, and how they function;
2. Identifying the control variables and their functional relationships to each other;
3. Specifying the elements of the system state and the manner in which changes in the control variables, mixed with the other inputs, transform or change these elements:

4. Evaluating the output (changed state).

II. Executive (Decision) Phase

1. Structuring the output for decision making and
2. Generating alternative changes in the Control variables.

The chart on the next page describes part I; an additional chart further on describes part II. The following pages describe the variables and functional relationships in more detail.

Part I

Fixed Elements, External Influences Described

The Fixed elements (fixed in that they are "givens" to the transit system, which has no control over them) are:

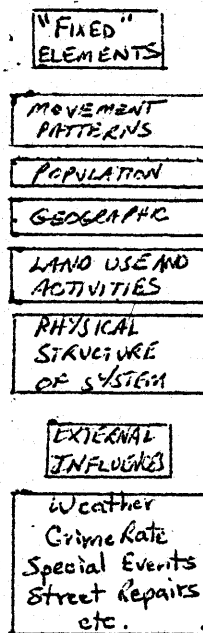
Movement data: Overall (total) travel patterns and destinations by all modes as reflected in available home-interview, cordon, post-card and stationary tallies.

Population data: United States Census data on totals, income, automobile ownership, ethnic grouping; growth or decline.

Geographic data: Homogeneous housing and/or activities by sectors, natural or man-made boundaries.

Physical structure of system: (right-of-way, stations, trackage, streets, gradients)

Land Use and Activities: defined in maps, surveys, etc.



STATE OF SYSTEM VARIABLES

SCHEDULED HEADWAY (FREQUENCY)	SCHEDULED RUNNING TIME (SPEED)	SCHEDULED LOAD (COMFORT)
ACTUAL HEADWAY (RELIABILITY)	ACTUAL RUNNING TIME	ACTUAL LOAD
DEMAND (TOTAL)	TRANSFER VOLUMES	UNSERVED ORIGINS AND DESTINATIONS OR ACTIVITY NODES
WORK PROGRAM	MILEAGE	

CONTROL VARIABLES

HEADWAY	VEHICLES
RUNNING TIME	TERMINAL TIME
ROUTE	SUPERVISION AND CONTROL

OUTPUT (NEW STATE) Δ OR TOT

FREQUENCY
SPEED
COMFORT
HEADWAY
RUNNING TIME
LOAD
DEMAND
TRANSFERS
UNSERVED
WORK PROGRAM
MILEAGE
Capital Costs

UTILITY or VALUE FUNCTIONS Δ OR TOT.

MANPOWER COST
MILEAGE COST
REVENUE
Non-mandatory costs

EVALUATION OF CHANGE

Viewpoint of
Transit System Community

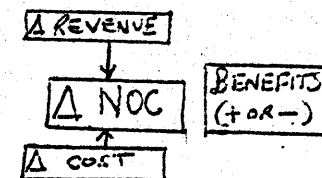


FIGURE 1

MODEL OF SCHEDULE AND ROUTE PLANNING PROCESS
PART I: TRANSFORMATION OF SYSTEM STATE BY CONTROL VARIABLES

The External influences include elements of the environment which are neither fixed nor controlled by the agency. These are:

Weather

Crime rate

Special events (parades, ballgames, etc.)

Disasters and emergencies

Street repairs and congestion

These elements often have significant effects on the actual load, headway and running time, hence on the reliability of the service.

Both fixed and external elements enter into the functional relationships in the model as specified further on.

Control Variables Described

The variables under the control of the transit agency will be classified into two groups which affect the State of the transit system:

I. Those which are mutually dependent or inter-related; for which functional relationships (especially concerning demand) are available; and over which immediate control (change) is possible (say in 0 to 6 months).

II. Those which are usually independent of each other; for which functional relationships are often not complete at present; and which often take more than six months to effect.

Examples of group I would be headway or running time; of group II, air conditioning of vehicles.

The control variables in the model fall in group I. They affect the schedule and route of a line. They are:

1. Route, or location: Described by the terminal(s), streets and bus stops, or by the right of way and station stops, turnback facilities, intermediate and terminal (location and capacity), line capacity; and physical or transfer interchanges. The Route is not dependent on (functionally related to) the other Control variables, although it is a function of certain fixed elements. That is, a change in Headway will not cause a change in Route to occur, while a change in the physical structure of the system will; and a change in population, movement or land use patterns might require a change in the Route.

2. Headway: Described by the scheduled interval between vehicles and/or trains, by homogeneous time periods,¹ by route, by length of train, by scheduled connections with other vehicles or trains.

3. Running time: Describing the scheduled time between terminals and intermediate points, stops or stations, for each route; by homogeneous time periods.¹

4. Terminal time: Describing the scheduled standing or "layover" or "recovery" time at final or intermediate terminals, to satisfy the minimum required by union agreement, and to allow for recouping of delays along the line.

5. Number of Vehicles: By route, time period.

Headway, Running time, Terminal time and Vehicles are inter-related by the following functions:

$$\text{VEH} = c(\text{RNT} + \text{TMT}) / \text{HWY} = k(\text{TLN})$$

$$\text{HWY} = c(\text{RNT} + \text{TMT}) / \text{VEH}$$

$$\text{RNT} = c(\text{HWY} \times \text{VEH} - \text{TMT}) = k(\text{RTE})$$

$$\text{TMT} = c(\text{HWY} \times \text{VEH} - \text{RNT}) = k(\text{CON})$$

Where VEH = Vehicles, HWY = Headway, RNT = Running time, TMT = Terminal time, RTE = Route, CON = Supervisory and Control (see below), and TLN = Train length; c and k are constants. Thus for example, an increase in Headway (less frequent service), holding Running time and Terminal time constant on the same route, would require a decrease in the number of vehicles.

6. Supervisory and Control measures: Not dependent on any of the other variables (although affecting the Terminal time in many cases), these measures affect the actual load, running time and headway (i.e., schedule performance) by means of number and placement of dispatchers (street or platform supervision), passenger flow devices, communications on-line, and the use of "gap" crews and vehicles (non-scheduled to fill in variable gaps in service).

Reliability, or the dependability and regularity of the actual headway, running time and load (as compared to the scheduled Headway, Running Time and Load) is not directly controlled by the company. It is, like cost, an effect of both the control variables and of external influences. Comfort and crowding, or Load, is in a similar category. Both are therefore assigned to the State and Output (transformed state) vectors.

Control variables listed above form a vector of inter-related controls which the transit company applies to the State of the system in order to change it. Often it is desired to know the Δ (incremental) change in the State as the result of an Δ (incremental) change in one or more Control variables.

The model is addressed primarily to this question of marginal analysis, or the effects of additions or subtractions to the existing system, as a means towards optimizing the operation.

The way in which the Control variables affect the State is described by a set of Transformation functions. One or more of these functions correspond to each State element, and at once define these elements and their relation to the Control variables. A brief description of each follows (a more detailed discussion of the analysis of state variables is the subject of chapter 7).

State Variables Described

Scheduled Headway or Frequency

A function of Headway or Vehicles. As a measure of flow, $\text{Frequency} = 60/\text{Headway (minutes)} = \text{Vehicles/hour}$. As a measure of average wait, $\text{Frequency} = \frac{1}{2} \text{ Headway}$.

Scheduled Running Time or Speed

$\text{Speed} = \text{Route mileage}/\text{Running time in hours (miles/hour)}$.

Load or Comfort

$\text{Load} = \text{Passengers}/(\text{Vehicle} \times \text{Seats})$, per vehicle, and/or $\text{Passengers}/(\text{Vehicle} \times \text{Capacity})$, per vehicle.

This is the percentage of available seats, of standing passengers, or of remaining capacity, scheduled. It thus depends on the scheduled headway, reflected in the appearance of the variable Vehicle in the function.

Actual Load

The actual load, along with the actual headway and the actual running and terminal times, is a function of both the Control variable Control (Supervisory and Control measures) and External influences, as well as of Scheduled Load. All three "actual" variables are measures of reliability. In general, surveys by transit agencies have shown that the heavier the scheduled load per vehicle, particularly in bus service, the more variation there will be in all three "actual" measurements. Also, the less variation provided in the Control variables to adapt to known variations in External conditions, the more variation there will be in actual load, headway and running time.

Actual Load measures the variation in Load over time (see figure 2) and train (see figure 3) and thus computes the actual percent standing.

Actual Headway

The Actual Headway is computed by taking the variation in observed headways in a given time period (see figure 4) and weighting by the number of passengers on each vehicle, to give the actual average perceived headway. Measures of the variation, limits, and intervals exceeding $X\%$ higher than the Scheduled Headway are also obtained.

FIGURE 2
VARIATION IN ACTUAL LOAD OVER TIME

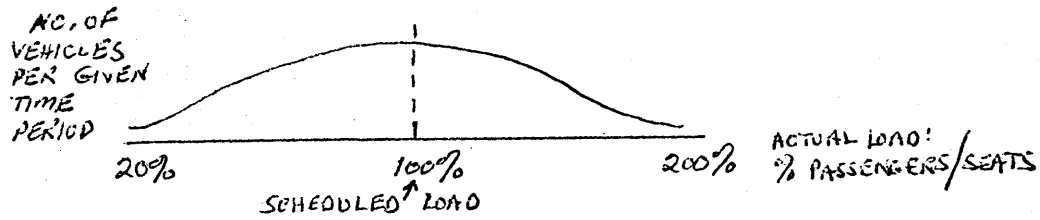
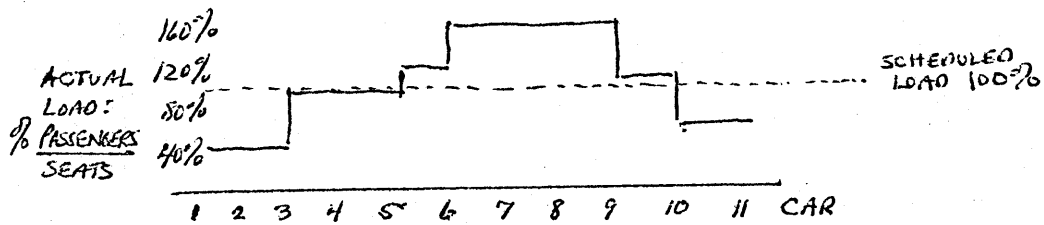


FIGURE 3
VARIATION IN ACTUAL LOAD OVER TRAIN



Actual Headway = function of (Headway, Load, External, Running Time, Control).

Actual Running Time and Actual Terminal Time

refers to the variation per interval of time compared to the scheduled Running time and Terminal time, and will show the percentage of intervals whose Actual Running time exceeds the combined Scheduled Running and Terminal times (see figure 5). It is a function of (Running time, Terminal time, Control, External and Load).

Demand

Demand = function of (Frequency, Speed, Comfort, Route, Fixed, and External), where Route is in turn a function of Destinations served, Population within walking distance, and Transfers. Thus, in theory,

$DEM_{rnt} / X \text{ pop. within } Y \text{ walking distance}$
 $= (\text{inc}^c \text{ or } \text{auto}^k \text{ load}^l \text{tnf}^j (\text{dest/O\&D})^{m_{ext}}) / \text{Headway}$
 per homogeneous time period, where $\text{dest/O\&D} \rightarrow \text{or } \text{dest/O\&D}^n$

DEM_{rnt} = separate demand curves for various running times

pop. = population

inc or auto = income or automobile ownership classes

tnf = transfers

dest/O&D = destinations served by the service compared to all origins and destinations of the population.

FIGURE 4

VARIATION IN ACTUAL HEADWAY IN GIVEN TIME PERIOD

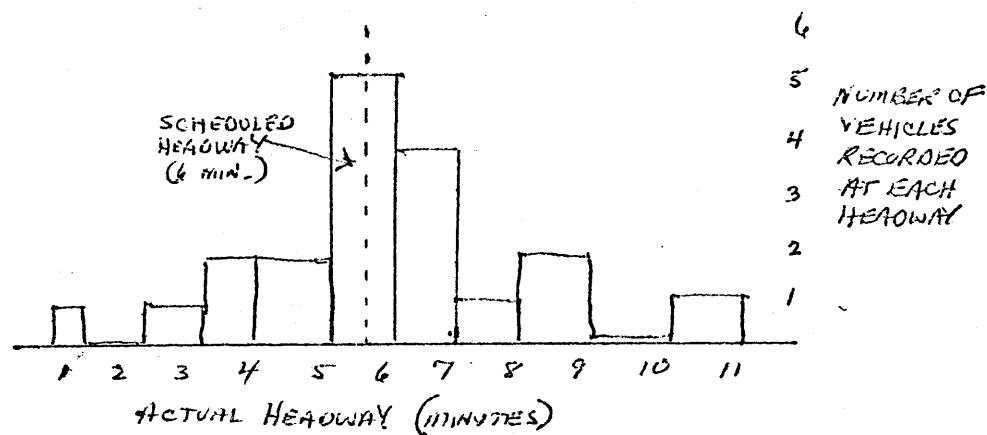
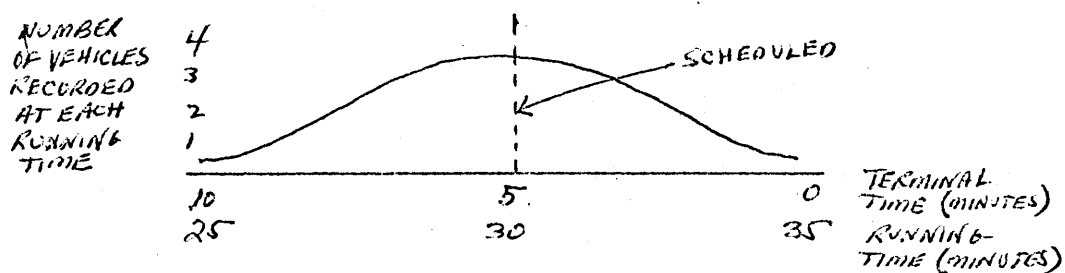


FIGURE 5

VARIATION IN ACTUAL RUNNING TIME AND ACTUAL TERMINAL TIME IN GIVEN TIME PERIOD



ext = External influences

c, k, i, j, l, m = constants

(See figure 6).

The demand functions actually presented in the next chapter will be estimates or best guesses on the basis of data available in Boston and New York, and from Demonstration experiments. They will not be assumed to have predictive validity. The functions relating demand to Headway will be based on regression curves developed previously by the author.² A sample equation (used for the table further on in this chapter) is:

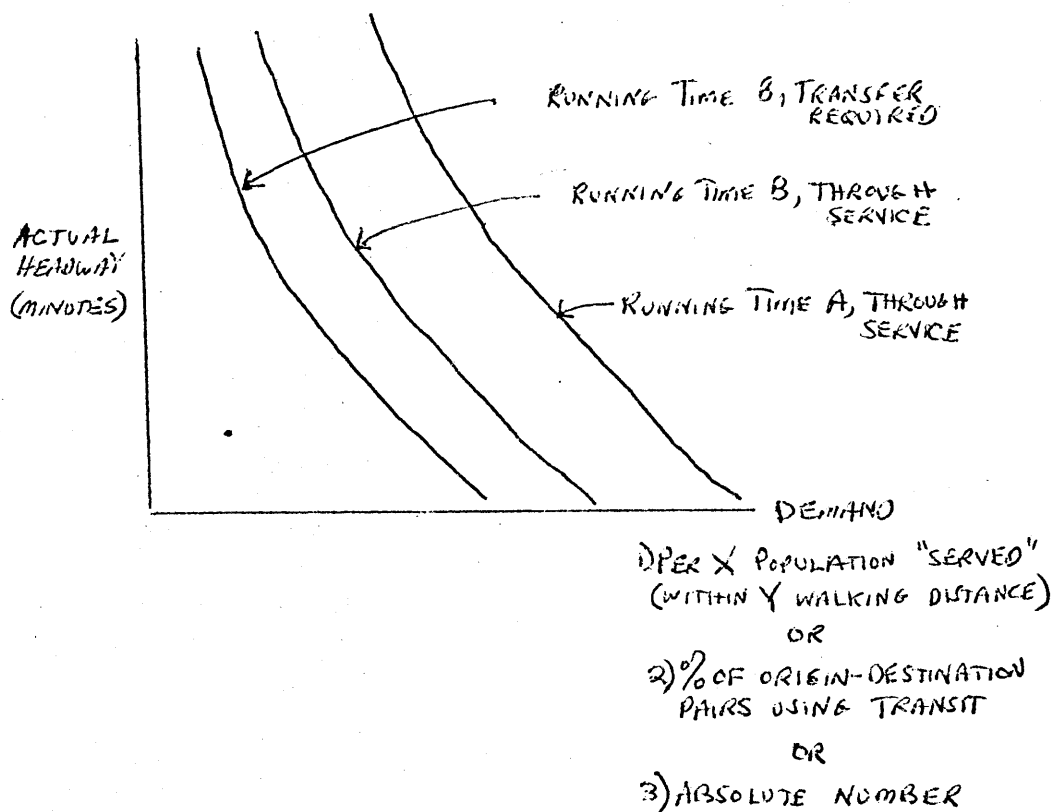
Passengers/1000 served $\frac{1}{4}$ mile walk, 4 hour period
inbound 10:00 A.M. - 2:00 P.M. feeder = $80.65 -$
 2.18 (Headway).

Work Program

The Work Program divides the trips (determined by the headway and running time) scheduled for each route into a Man's work day according to

- terminal time (layover) for the crew or operator
- lunch allowances
- report, sign off, transfer of vehicles from storage areas to nearest route point time allowances
- special rules for swing (gap of two or more hours between first and second parts of day's work) runs and piece (less than a full day's work) runs
- overtime pay and guarantees

FIGURE 6
HYPOTHETICAL DEMAND FUNCTION



MID-DAY 10:00 AM TO 3:30 PM
Bus Feeder to Rapid Transit Station
NO SCHOOL

SEAT-GETTING PROBABILITY 100%
INCOME RANGE D (\$500-9900)

Two kinds of measures are required: one, the number of men or crews, can be estimated for an entire 24 hour schedule by this rough formula:

$$\#Men = \frac{\#trips \left(\begin{array}{l} \text{Running + Terminal time + Allowance \&} \\ \text{in hours} \qquad \qquad \qquad \text{Guarantee} \end{array} \right)}{\text{Work day (in hours)}}$$

+ (for schedules requiring swing or piece runs)
 $\frac{1}{2}$ the peak vehicle requirement less the base vehicle requirement.

The only truly accurate measure of the manpower requirement, however, is the revised work program.

The second kind of measure is that of Work Program Efficiency. This would require these measures:

- Percent of paid hours actually worked
- Percent of total round trip time in terminal
- Excess of terminal time, lunch, etc., over minimum required by contract
- Excess lateness and resultant overtime payments.

Mileage

Mileage = #trips (route mileage) plus an added percentage for non-revenue mileage in yards, or to and from depots. Measures of mileage efficiency would be revenue per mile, miles per crew or operator, etc.

Transfer Volumes

These are a function of both the Route and Fixed Elements, and are expressed as an absolute number of passengers or as a percentage of the total on a vehicle transferring at a given point, or as a percentage of the total passengers on a given route transferring to or from other routes, etc.

Unserved Origins & Destinations or Activity Nodes

These are also a function of Route and Fixed Elements, and are determined by comparison of origin and destination data and map and population analysis to the routes. Unserved trips could be those link-ages not served at all, or those with a modal split unfavorable to the transit system.

These State variables, when changed by manipulation of the Control variables, become the Output. They may be expressed as absolute numbers: for example, Frequency changed from 8 to 10 minutes; or as increments: Work Program + 5 men. How any State variable is changed into its associated Output is determined by its functional relationships with the Control variables and the input (Fixed and External) variables on which each State variable depends.

Value Functions Described

The values assigned to the Output are determined only in the case of the manpower in the Work Program and the Mileage and Vehicle requirements, for which cost functions will be developed in chapter 6; and for Demand (see chapter 5), which multiplied by the fare gives Revenue.

The cost functions to be derived from the analysis of data in New York (and to the extent possible, Boston) will have the approximate functional forms:

$$\text{Maintenance of Equipment Cost} = c_{\text{spd}} \text{Mlg} + k \text{Mlg} + r \text{Veh}$$

$$\text{Power Cost} = f(\text{Spd}, \text{Stops}, \text{etc.})$$

(where Stops = stops per mile or per route)

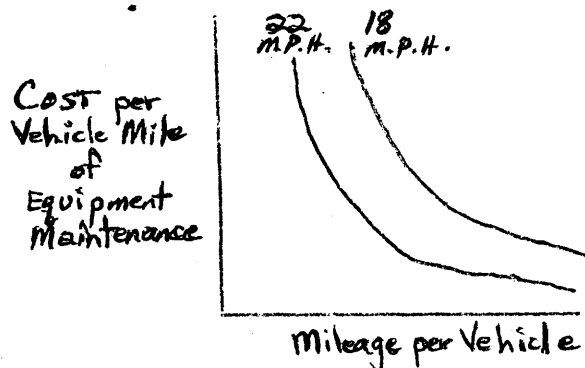
$$\text{Maintenance of Way Cost} = c_{\text{spd}} \text{Mlg} + k_{\text{vol-wt}} \text{Mlg} \\ + \text{location} + \text{External}$$

Accident & Insurance Cost = $f(\text{Passengers}, \text{Spd}, \text{Mlg})$

Where Mlg = mileage, Spd = speed, Veh = vehicles, Vol-wt. = ton-miles (vehicle) per track or street mile and is in turn a function of Load, Location = underground, open cut, elevated; and c, k, r = constants.

The cost function for equipment maintenance on a system with sufficient variation in shop size or seasonal mileage to show economies of scale with increasing mileage might look something like figure 7.

FIGURE 7
EQUIPMENT MAINTENANCE COST PER VEHICLE MILE RELATED TO SPEED AND MILEAGE



Other functions, such as power costs, might better be expressed in tables computed from analysis of rate schedules and route alignments. In some, speed or mileage may not be a variable.

Capital costs resulting from changes in Control, Vehicle or Route; and the demand in number of passengers times the fare are the other variables to which monetary value can be assigned. The costs and revenues for each change form the Net Operating Contribution (NOC) vector (see next page).

The remaining Output is at least in theory capable of taking values comparable to the dollars and cents of cost and revenue; but the values are presently unknown. They comprise the positive or negative Benefits which, if they could be expressed in dollars and cents, could be compared to NOC.

Part II
EXECUTIVE (DECISION) PHASE

NOC (Net Operating Contribution to overhead and profits) is in practice the most commonly used measure of either profit maximization or constraint on other goals. Total NOC for one or more routes or schedules = Revenue less Variable Cost (not total cost).

Marginal NOC consists of the cost and revenue increment of each change. That is, marginal NOC is the actual (not the absolute) value of the difference between the added (not average or total) cost and the added (-or+) revenue per unit change in (any) control variable. As long as marginal NOC is increasing (even if by ever smaller amounts) total NOC is increasing and the change puts the company in a better position.

The point of maximum total NOC and optimal marginal NOC per unit control variable is where $MR = MC = MNOC = 0$ (marginal revenue, cost and NOC all = 0). Graphically, the slope at this point (= marginal NOC) levels out (= 0) and there is a peak on the curve (see figure 8). Any movement in either direction from this point of maximum total NOC per unit control variable will in theory result in an increase in marginal net cost (that is, the marginal cost

will be greater than the marginal revenue). For example, if maximum total NOC occurs at an 8 minute headway, a shift to either a 7 or a 9 minute headway will result in a negative marginal NOC.

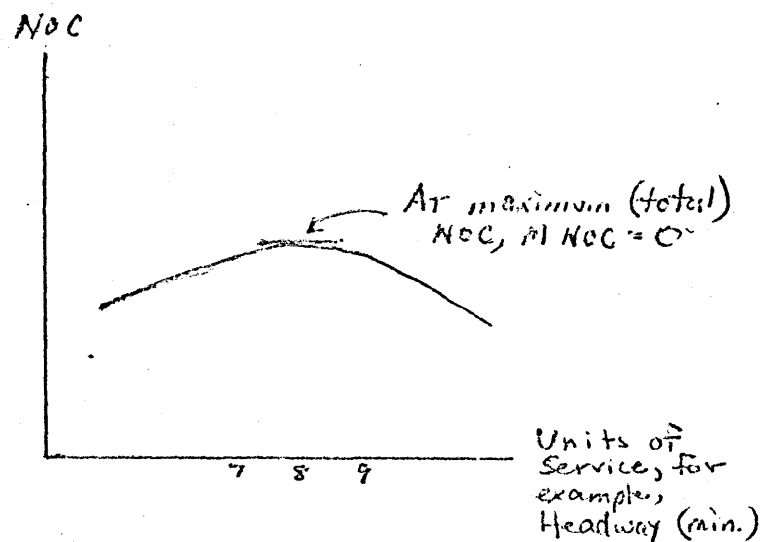


FIGURE 8
MAXIMUM TOTAL NOC

Often, however, the company may wish to satisfy some objective other than profit maximization, perhaps maximum demand subject to a minimum acceptable total NOC. In the above example, although a 7 minute headway may have a negative marginal NOC, the total NOC may still be positive and above the minimum acceptable to the company, and the demand will be greater. In addition, there may be several points at which marginal NOC = 0, only one of which represents a maximum total NOC. These conditions

are further discussed in the following pages.

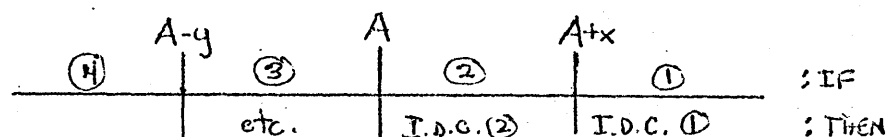
The valuation of NOC and Benefits (or their proxy Output) is both the means of decision and of generating alternatives. The transit agency must set acceptable levels for the State variables in the absence of complete information on Benefits. This decision and choice part of the process is iterative, and works through the following procedure (see Figure 9):

Step 1 - Identification of State variable calling for change (Initial Directive Criteria).

The State variables described earlier are subjected to criteria which are set, in some cases by purely arbitrary subjective or political means, by the transit company. In other cases, continued experience with the model will suggest these first order constraints, as for example a non-rush hour Load above which any more crowded condition always results in more revenue loss than cost savings.

An example of this first step for the State variable Mileage (here as Revenue per Car Mile) is:

<u>If STATE Variable Rev. per CARMile</u>	<u>Then</u>
1) $\geq A+x$	reduce headway one unit (minute)
2) $A < \text{Rev./Car Mi.} < A+x$	do nothing
3) $A \geq \text{Rev./Car Mi.} \geq A-y$	increase via positive changes in relevant control Var. (do not service)
4) $\text{Rev./Car Mi.} < A-y$	increase (Rev/CM, as above) to A-y or better, subject to constraints on minimum service



Where A = system average

$A + x$ = maximum above which too heavy loading is indicated

$A - y$ = minimum acceptable to company (at or at least below which there is usually no possibility of an improvement in service producing a positive marginal NOC).

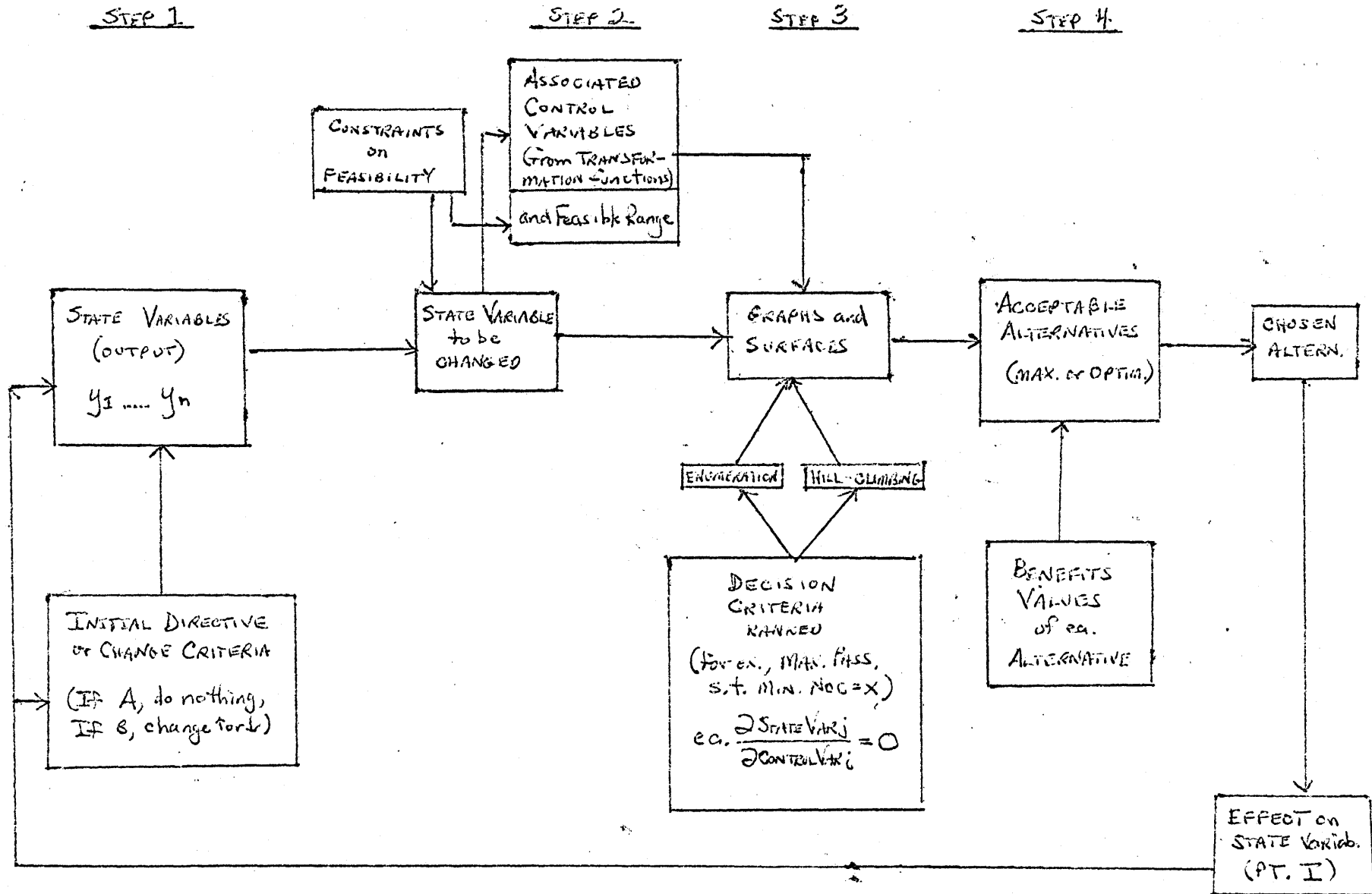
(In the event that all such initial directive criteria are satisfied - that is, call for doing nothing - the company can still bypass the directives and continue with the analysis if it wishes).

Initial Directive Criteria for each State variable are discussed in chapter 7, and a possible set of such criteria is listed in chapter 8.

Step 2 - Choice of Control variables necessary to change State variables.

Each Output or State variable has a function relating it to specific Control variables (see part I). The

FIGURE 9
MODEL OF SCHEDULE AND ROUTE PLANNING PROCESS
PART II : EXECUTIVE (DECISION) PHASE



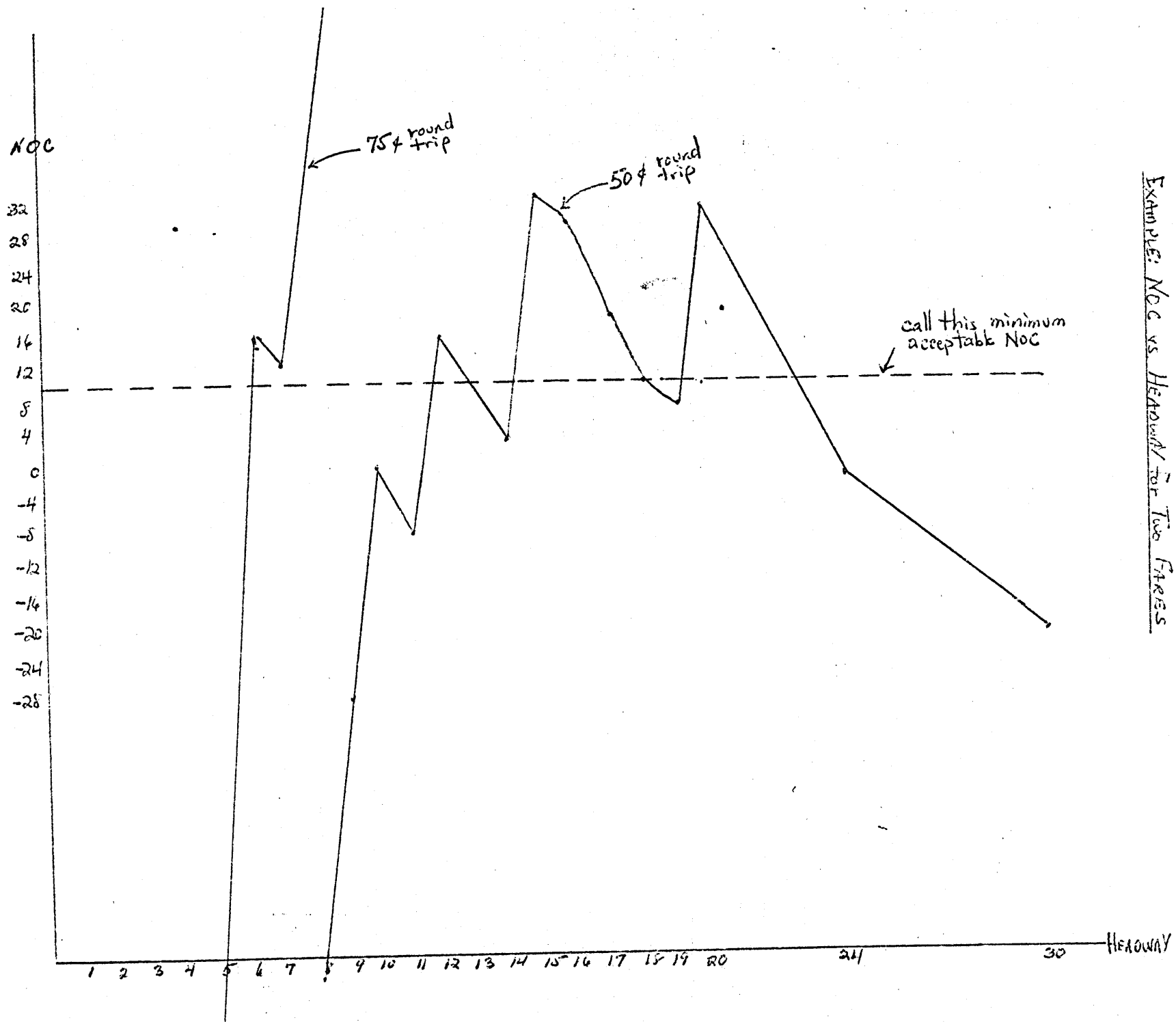
functions are by unit (feasible) steps. For example, Headway is measured in units of one half minute.

For each unsatisfied Initial Directive Criterion, the function belonging to the State variable evaluated will contain the Control variables that can be changed to effect a change in the State variable. Each must be examined (see step 3). Some control variables can be eliminated from specific situations by means of operational constraints. For example, if there is no terminal capacity at a turn-around point, Terminal time may be eliminated as an operable Control variable for that point.

Step 3 - Evaluation of effects of various possible Control variable changes on State variables.

The values of NOC (Net Operating Contribution) associated with each unit change in one control variable can be displayed singly and in combination over their feasible ranges in graphs. These graphs (see figure 10) are derived from the Value functions. By applying the stipulated criteria (for example, maximum total NOC) to a single input variable graph, a decision point will be located. The altered output (new State variable) would then be resubjected to the Initial Directive Criteria (Step 1).

In theory, when two or more Control variables are input, a surface, rather than a graph, is formed. Setting each $\frac{\partial \text{State Variable}}{\partial \text{Control Variable}} = 0$ will give one or more maximum outputs associated with each change. On each iteration the Control variable(s) chosen would be the one(s) whose partial



<u>HWY</u>	<u>VEH</u>	<u>TPS</u> <u>8hrs.</u>	<u>MLG</u>	⁵ <u>VEH</u> <u>x\$32</u>	⁶ <u>MLG</u> <u>x40¢</u>	<u>COST</u>	⁷ <u>4hrs</u> <u>PASS/</u> <u>1000</u>	<u>@6000</u> <u>x2(4-</u> <u>8hrs)</u>	<u>x50¢</u> <u>2way</u> <u>REV</u>	<u>NOC</u>	⁸ <u>x.75</u> <u>PASS</u>	<u>REV</u>	<u>NOC</u>	<u>HWY</u>
5	12	96	960	384	384	768	88	1056	528	-(240)	880	660	-(108)	5
6	10	80	800	320	320	640	82	984	492	-(148)	820	615	-(25)	6
6½	9	74	740	288	296	584	80	960	480	-(104)	800	600	16	6½
7	9	69	690	288	276	564	77	924	462	-(102)	770	577	13	7
8	8	60	600	256	240	496	72	864	432	-(64)	720	540	44	8
9	7	53	530	224	212	436	68	816	408	-(28)	680	510	74	9
10	6	48	480	192	192	384	64	768	384	-(0)	640	480	96	10
11	6	44	440	192	176	368	60	720	360	-(8)				
12	5	40	400	160	160	320	56	672	336	16				
13	5	37	370	160	148	308	53	636	318	10				
14	5	34	340	160	136	296	50	600	300	4				
15	4	32	320	128	128	256	48	576	288	32				
16	4	30	300	128	120	248	46	552	276	28				
17	4	28	280	128	112	240	43	516	258	18				
18	4	27	270	128	108	236	41	492	246	10				
19	4	25	250	128	100	228	39	468	234	6				
20	3	24	240	96	96	192	37	444	222	30				
24	3	20	200	96	80	176	29	348	174	-(2)				
30	2	16	160	64	64	128	18	216	108	-(20)				

derivative at 0 yields the maximum output.

Ideally, the analyst would wish to range over the entire surface to find the "global" optimum, where for each State variable, NOC for example, $\frac{\partial (NOC)}{\partial \text{Con. Var.}_1} = \frac{\partial (NOC)}{\partial \text{Con. Var.}_2} = \dots = \frac{\partial (NOC)}{\partial \text{Con. Var.}_n} = 0$. However, the "global" optimum is not necessarily the sum of the local optimum points. By optimizing or taking maximum peaks from two graphs comprising a surface, or from setting each partial derivative equal to zero separately, one cannot be assured that the function describing the surface is thus optimized. Therefore, some means must be found for ranging over the surface to search for its behavior and lead to the global optimum point, where a change in any control variable will result in negative marginal change in any State Variable.

Such a point is clearly hypothetical, particularly since the values assignable to all State Variables are not known. But in approaching an approximation of this goal, or in dealing with sub-surfaces, the need is pointed up for one of two procedures to find the optimum:

1. Complete enumeration of all points which would yield the single optimum point. This is feasible in isolated problems like the one illustrated on the previous two pages. In the graph, there are three maximum points at the original fare that satisfy the criteria of minimum acceptable NOC of 10, but only one that additionally satisfies the criteria of maximizing passengers (subject to minimum NOC) or of maximizing NOC. The use of complete enumeration depends on the computational effort involved. Whether or not

the costs of calculation are worthwhile is a matter to be determined on the individual merits of the case.

2. Hill Climbing techniques, a search for the point or points where the second derivative (rate of change of the slope of the curve) is greatest as a guide towards the summits, eliminating the need for enumerating every point. The hill climbing method may omit some peaks, and can thus be said to lead to a better, but not necessarily best solution. However, in complex surfaces, the additional effort and cost of computing all points may not be worth the increment of the difference. Further research into the application of this method should be carried out.

Continuous hill climbing, or poking around the slopes and ledges, would eventually lead to complete enumeration. Thus the eventual process applied may have a combination of both features - approximation over part of the surface, and complete enumeration over the most sensitive or undulating parts of the surface.

At each step along the way, many alternatives will be ruled out as infeasible due to various External and Fixed factors and constraints. All alternatives that are politically or logistically feasible will be considered. Often, however, the agency must assign arbitrary values to conflicting alternatives (where one criterion calls for a change that violates another criterion).

Step 4

The final choice rests on the application of (presently unknown) Benefit or Value measures to the alternative

consequences. Whether to get the same NOC with 800 passengers at $37\frac{1}{2}\phi$ or 672 passengers at 25ϕ (one-way) in the above example depends on the value of diverting the extra 128 passengers to mass transit, in terms of trip price reduction for those 128, decreased traffic congestion, possible reduced need for additional highway or arterial construction. Often the final decision will depend on the balancing of intuited long-term effects of inadequate service against various degrees of loss or negative marginal NOC.

The foregoing chapter has presented a model of the Scheduling and Route Planning process in a somewhat theoretical framework. The next two chapters, chapters five and six, develop hypotheses and functions which will be used to determine the Value functions described in the model. Chapter 5 will deal with the effect of changes in State and Control variables on demand, thus providing a basis for estimating corresponding revenue changes. Chapter six will examine the variables in manpower and mileage costs associated with changes in the Control variables.

The practical application of the model is described in the last two chapters. Chapter seven develops appropriate Initial Directive Criteria and applicable alternatives for changing the State variables, based on the transformation functions described in this chapter and utilizing the relationships developed in chapters five and six. Chapter eight gives an example of the entire Scheduling and Route Planning process developed in the first seven chapters.

Footnotes

1. In general, a time period is homogeneous unto itself if there is no substantial change in either the rate of passenger flow or the headway. Divisions of the year, season, month, week, day and in some cases hour are all eligible homogeneous time periods within these requirements. See table 12, chapter 5.
2. The Effect of Quality of Service on Transit Usage in Boston and New York, Massachusetts Institute of Technology, Department of City and Regional Planning, research report (June 1965).
3. See chapter 6 for development of the cost functions.
4. See chapter 6 p. 232 ff.
5. At \$4.00 an hour, includes (approximately) allowances and guarantees for driver times 8 hours (assume the vehicles are available), Boston, 1965. (1967 costs are up to \$5.25 an hour, see chapter 6).
6. Approximate variable cost in 1965, Boston.
7. From chapter 5, Passengers per 1000 served in four hour period inbound 10:00AM to 2:00 PM = 80.65 -- 2.18 (Headway). Adjusted here by hand at ends of curve to illustrate curvilinear effect in data.
8. Reduced by standard transit formula: for every 1% increase in fare there is a .33% decrease in passengers. Hence, the 50% increase in fare would cause a 16.66% decrease in passengers. See chapter 5 p. 189.

CHAPTER V
ESTIMATION OF CHANGES IN DEMAND

CHAPTER V

Estimation of Changes in Demand

In this chapter, a review will be made of selected typical published research on models of modal split and demand for transit service, emphasizing those which treat level of service as a variable; a series of hypotheses will then be presented, prefaced by a theoretical statement on the demand for transit service, and tested statistically. The purpose of this chapter is to demonstrate both the need for and the validity of the kinds of hypotheses developed, in the scheduling process.¹

Modal Split Models

Modal split is the proportion of travelers using each available mode of transportation within a given temporal and spatial framework (for instance, the number of work trips in Boston made each weekday by automobile, bus, rapid transit, streetcar, bicycle, motorcycle, foot, etc.). The study of modal split, and the reasons for it, has occupied an important place in urban transportation research.

Early metropolitan transportation studies and methods either ignored or were unable to handle the effects of quality of service on modal split. In effect, they assumed that the relative quality of service would not change over time. For example, Chicago², Pittsburgh,³ and Vancouver⁴ based their modal split predictions on car ownership, population density, intensity of land use and distance from the Central Business District. Leo F. Schnore⁵ has suggested that the size, density and age of a city explain present modal

Table 1

Summary Comparison of Various Approaches To
Modal Split Problem

<u>Proponent</u>	<u>Factors Included</u>					<u>Excess Cost</u>		
	<u>Demographic & Geographic</u>	<u>Size & Age</u>	<u>In- come</u>	<u>Transit Svc. (gen.)</u>	<u>Time</u>	<u>Cost</u>	<u>& Time, Comfort, etc.</u>	
Chicago ²	x							
Pittsburgh ³	x							
Vancouver ⁴	x							
Schnore ⁵	x	x						
Detroit ⁶	(No Modal Split Eq.)							
Twin-Cities ⁹	x			✓				
Levinson & Wynn ¹⁰	x			x				
Adams ¹¹	x			x				
Mortimer ¹²	x				x			
Delaware Port ¹³	x				x			
Smith ¹⁴	x		x		x	✓	✓	
Martin, Memmot & Bone ¹⁵					x	x		
Penn-Jersey ¹⁶	x		x			x		
Peat-Marwick ¹⁷	x		x		x	x	x	
Charles River ²⁰	x		x		x	x	x	

✓ Means recognized as a factor but not included in determining
Modal split

split. (Detroit⁶ did not even study modal split). These models do show variations in modal choice based on the postulated variables. The models are probably valid given that the level of service is held constant.

It is, of course, possible to show the symmetry between growth in automobile registration and decline in transit riding. There is no question that many mass-transit passengers have been lost in the last twenty years to the superior service qualities of the automobile, including some very hard to define psychological and sociological quantities. But holding the above variables constant and changing the quality of transit service does alter the modal split. This has been documented for major service changes, such as the introduction of rail rapid transit into areas previously without it. Of the riders using newly opened rapid transit lines, 37% in Boston and 26% in Chicago were former automobile travelers.⁷ Smaller, operational changes in service, such as frequency of service or fares, can also produce changes in modal split, as a number of Federal Mass Transportation Demonstration Experiments⁸ have shown.

Few people would question the statement that quality of service in a public transportation system also affects the demand for transit service. Opinion becomes more diverse, however, in assessing the quantity and significance of increased patronage. How many additional riders will be attracted, where will they come from, will the

cost of improving the service be compensated for; how much of a difference will the shift make in the design and use of alternate transportation facilities, and in the viability of the core area of the city?

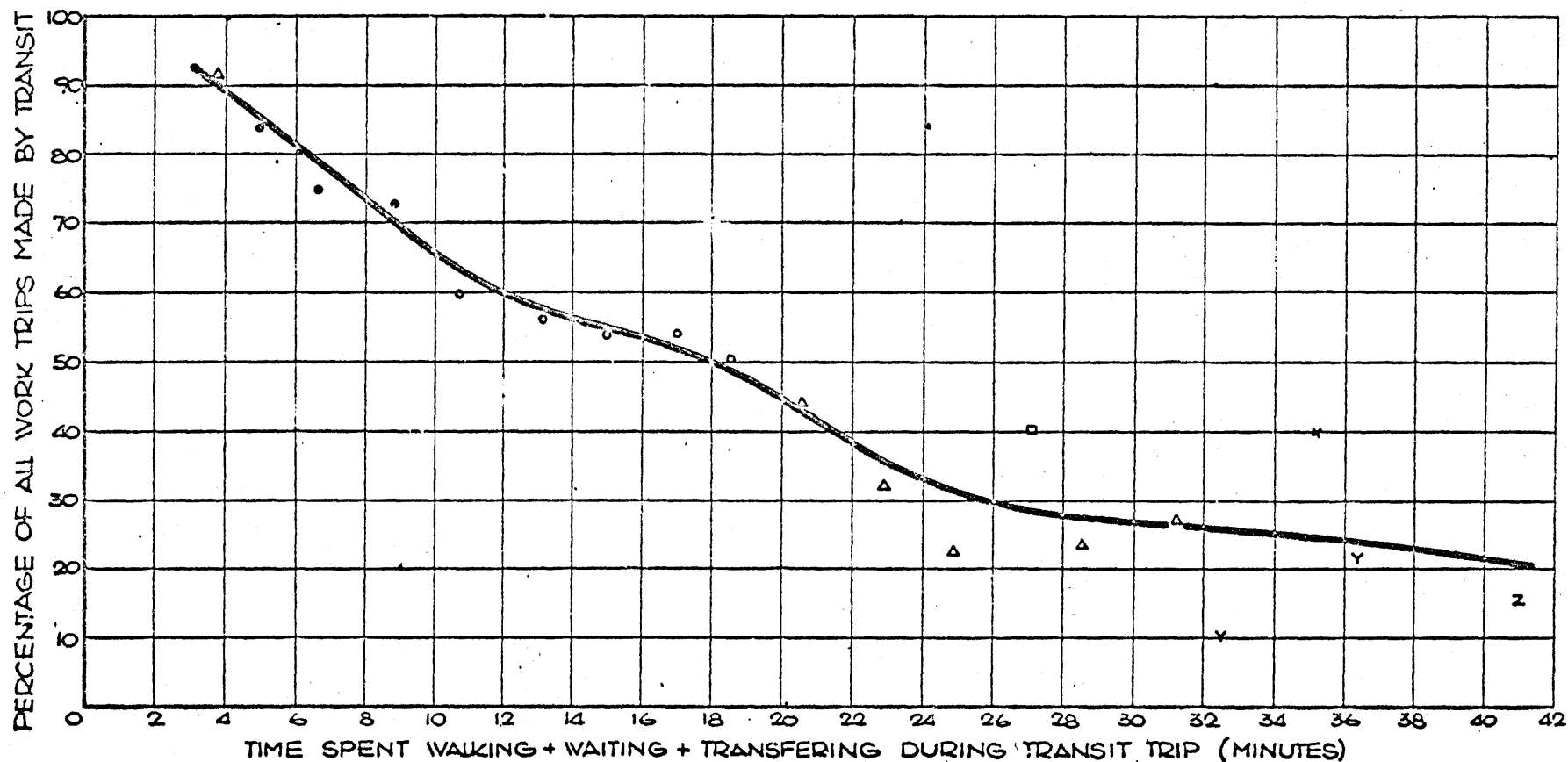
The 1963 Twin-Cities Transportation Study⁹ recognized the role of transit service quality, but found no way to express it. Herbert S. Levinson and E. Houston Wynn¹⁰ included a formula for the effect of transit service, but it was not considered an important parameter. Warren T. Adams¹¹ used a "Transit Service Ratio" as one of his factors; this was a composite measure of vehicle miles, average speed and terminal factor for the entire city.

More recent attempts to measure the effect of quality of service on modal split have been adaptations to public transit models of time diversion curves used in highway assignments. William J. Mortimer¹² derived such relationships for the Chicago area. He found through a sample survey that time was the important factor in 42% of modal choice decisions. Mortimer determined that if transit were twice as fast as the automobile in Cook County, 85% would go by transit to the Central Business District; if equal in time, 62% to the C.B.D., and 42% for all trips; if half again as long as automobile time, then only 35% of C.B.D. trips and 18% of all trips would be by transit. The Delaware River Port Authority¹³ derived such curves for several cities, and then made one for their own area.

Time is not the only variable confronting the traveler. In Mortimer's study, almost 60% of the respondents had

RELATED TO TOTAL WALKING AND WAITING TIMES

z NUMBER OF WORK TRIPS BTW. 0 - 200 □ NUMBER OF WORK TRIPS BTW. 1000 - 2500
 y 200 - 500 △ 2500 - 10000
 x 500 - 1000 • 10000 - 50000
 • NUMBER OF WORK TRIPS OVER 50000



TRAFFIC RESEARCH CORPORATION

PROJECT: 2010-Q30

DATE: NOV. 1961

FIGURE 1

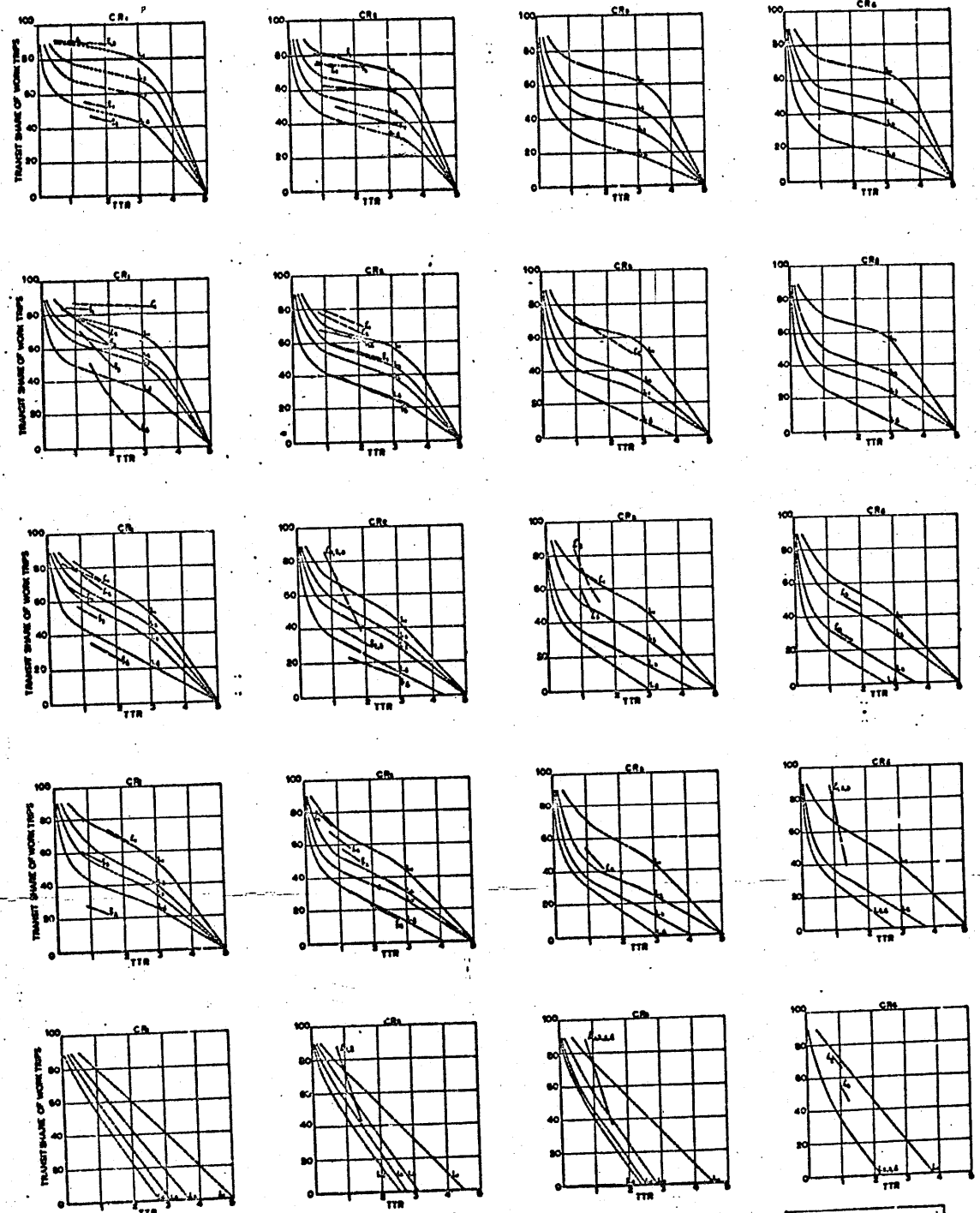
PLATE: II

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FIGURE 2

FIGURE 2: WORK TRIP MODAL SPLIT RELATIONSHIPS WITH ADJUSTED EXTRAPOLATIONS

Deen, Irvin, Martin



MODAL SPLIT RELATIONSHIPS ESTIMATED
FOR THE METRO AREA OF PHILADELPHIA
TIME RATIO : TTR
COST RATIO : CR
SERVICE RATIO : SR
ECONOMIC STATUS : EC

LEGEND:
WASHINGTON : L
PHILADELPHIA : M
TORONTO : S

other reasons for choosing their modes of travel.

Wilbur Smith, in his work for the National Capital

¹⁴ Region recognized cost and comfort (as well as frequency, directness and speed) as important, but assumed them to be equal on all modes and used simple time-ratio curves.

Smith made an attempt to relate time ratios to income of users (with the obvious result that time is worth more to those with higher income). Brian Martin, F. Memmot and A.

¹⁵ Bone speak of the effect of cost and time, and of various kinds of diversion curves. ¹⁶ The Penn-Jersey study used "cost" of travel, along with income, land density and car ownership to predict modal split.

Peat, Marwick and Livingston, formerly Traffic Research Corporation, has developed a more comprehensive approach in recognizing and quantifying quality of service as a main determinant of modal choice, stratified by user characteristics. ¹⁷ In their model, in addition to time and cost, convenience is measured by summing waiting time (half the headway), transfer time (half the headway of the second vehicle), and walking time, for which a formula is used involving walking speed, spacing of loading points, number of acres of developed land, and number of miles of transit track or bus route. These are then stratified by income (see fig. 1 & 2). Income is defined as the most effective measure of market (user) characteristics; it is suggested that the variables used in earlier transportation studies are linearly related to income or quality of service.

Of the nine modal split methods documented in a recent Bureau of Public Roads publication ¹⁸, only the

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Traffic Research Corporation model uses these measures of "excess" time. It is interesting to note that research at the Transportation Center at Northwestern University, although treating only time and cost as determinant variables, has shown that even income may not always be important - that, in short, the relative service characteristics may often be the deciding factors.¹⁹

Charles River Associates of Cambridge has developed an econometric model, using measures of elasticity and including "excess" time and cost weights.²⁰ Separate elasticities by trip purpose were developed for fare, excess cost, line haul time and excess time. (see table 2). The model was calibrated on origin and destination home interview data collected for the Boston Regional Planning Project in 1963.²¹ An additional feature of this model is its ability to generate new trips (as opposed to simply diverting existing trips from one mode to another) as a result of changes in the service characteristics of a mode.²²

The use of "excess" costs and times is a step in the direction of a more realistic portrayal of the process of modal choice. Parameters such as speed or expected travel time permit a comparison with automobile transportation, but do not reflect the essential difference between private and public transportation: one is continuous, leaving at will and proceeding without interruption until the destination; the other is inherently discrete, operating on fixed routes at scheduled times and thus enforcing delays and transfers.

The inherent interruptions and uncertainties of public transportation are not adequately reflected by mean values of speed, time or cost.

Table 2

Elasticity of Passenger Travel Demand with Respect
to the Time and Cost of Transit Trips

Trip Purpose	Cost Elasticity		Time Elasticity	
	<u>Line Haul</u>	<u>Excess Cost</u>	<u>Line Haul</u>	<u>Excess Time</u>
Work	-.09	-.10	-.39	-.71
Shopping		-.323		-.593

Source: Domencich et. al., op. cit. (20) pages 30-31

Even with excess costs and times introduced as parameters, however, none of the above models is capable of accurate or relevant predictions in the manner sought for the methods being espoused here. Being calibrated on a metropolitan-area wide basis, the models ignore or smooth over many variations which on a line-by-line or even sub-area or zonal basis become important enough to invalidate the predictions.²³

While being useful for the design of a highway or transit route in general terms,²⁴ they do not give sufficiently precise answers to questions of incremental route changes, station or stop locations, frequency of service and so forth. Most important to the transit industry, they do not directly provide information on the effects of incremental changes in transit service within a stable pattern of origins and destinations, income distributions and highway network.

The emphasis in the development of these models has been and continues to be the search for a comprehensive, area-wide predictive capacity involving the entire transportation system network. The transit industry, however, needs a method of evaluating individual changes. This thesis addresses itself to the latter.

Fares and Travel Time

Because so relatively little exploration of the effect of service characteristics on demand has been done to date for public transportation, it seems possible to present their major results fairly briefly. The conclusions fall mainly into two categories: the effect of fares on traffic and the value of time.

The typical, and most widely accepted, description of the effect of changes in transit fares on demand is the rule developed by Simpson and Curtin²⁵ which predicts that ridership will decrease according to the following equation; where Y is the percent net change of traffic and X the percent fare change

$$Y = -0.30X - 0.80$$

with a regression coefficient, $R = 0.92$. The coefficient of X, which indicates the rate of loss in ridership due to fare changes, is known in the transit industry as the 'shrinkage ratio' or the 'loss ratio'. Repeated analyses for a wide range of American cities have demonstrated the general validity of this formula for contemporary urban mass transportation in the United States.

Experience derived from fare increases on major transit systems since 1952 suggests a lower loss ratio, however. In

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a survey of 11 cities, the ratios as low as 0.08 (Baltimore) were observed with values below 0.20 being common (San Francisco, New York, Boston, Philadelphia and Salt Lake City). Overall an average loss ratio of 0.22 for big cities, was registered. Curtin himself has thus recommended using 0.20, that is $Y = 0.20X$, as a planning estimate. Likewise, the recent 25% taxi fare raise in New York City resulted in a 4%²⁶ loss in traffic. This corresponds to a shrinkage ratio of 0.16, similar to Curtin's revised estimate.

Furthermore, as Schneider points out²⁷ on the basis of his analysis of experiments in Los Angeles with special fares for senior citizens, the Simpson and Curtin formula does not appear so useful in predicting the results on individual routes or for different classes of riders. It was observed in effect that the elasticity of demand with respect to price was significantly higher for elderly people than for the system as a whole. Greater, in other words, than as predicted by the Simpson and Curtin formula.

There is thus no one market for mass transit. The demands for a system's services are an aggregation of the equilibrium points established by the needs of diverse categories of riders; workers and shopper, rich and poor, school children and retirees. Some of these differential relationships have already been identified, as indicated previously in Table 2. The general trend that peak hour ridership was less affected by fare changes than off-peak demand was also recently observed in New York City.²⁸

This same study gave evidence of a significant difference in the impact of the fare change in low-income groups.²⁹ The threefold greater decrease in riding in the low-income areas is further confirmed by annual revenue tabulations for the first year after the fare rise, on both rapid transit and bus lines.³⁰ In contrast, virtually no change in riding was observed at rapid transit stations in the Central Business District turnstile registrations on the Broadway BMT Subway (excluding interdivisional free transfer stations) declined less than .05%.³¹

In this situation, a single formula may be useful as a means for predicting overall system ridership, but it is inadequate as an explanation of the detailed causal relationship between transport supply and demand.

Travel time is also an important determinant of modal choice, as suggested by table 1. It is usual practice, sanctioned by the Federal Bureau of Public Roads for example,³² to account for the effect of time by imputing to it a monetary value of some sort. J. F. Wardrop,³³ Stanley L. Warner,³⁴ Lowden Wingo³⁵ and Leon Moses³⁶ have all researched this "cost" of time, to name just a few.

Several recent studies indicate how the value of time is generally estimated. Thomas for example,³⁷ investigated the behavior of industrial workers at 8 localities in 5 states and recommended valuing time at the rate of \$2.82/hour/person. The analysis is based upon what seems to be

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really a fairly special market: commuters of above average income (\$9200/family). If the demand of this group is in fact relatively inelastic, as it appears, then it is not appropriate to generalize from them. In particular, these valuations are probably not suitable for an analysis of urban mass transit.

Other studies of the value of travel time, even the most recent ones, are not much different. Lisco, for example, has done an extensive analysis of the behavior of commuters in Skokie, Illinois, a small, upper-middle-income suburb on Chicago's North Side.³⁸ He reports a marginal value of time between \$2.40 to \$3.00 an hour. But he also suggests that these figures are most appropriate for commuters with incomes between \$10,000 to 17,000 a year, incomes above the national average. In fact, for lower income brackets - those that often predominate the central city and are major users of downtown mass transit services - Lisco indicates that appropriate values of time may be from \$0.40 to \$0.78 for people with incomes between \$4,000 and \$6,000.

Mass Transit Demonstrations

The immediate and most striking feature of the federal Urban Mass Transportation program is its diversity, as McGrath points out.³⁹ As of the beginning of 1967, about \$440 million of federal and local money has been spent and some 125 federal contracts ranging in size from 14,833 to \$23,420,000 have been let. Each city has been forced to determine and deal with its own needs as it sees them.

Each project is thus not only distinctly individual in concept but also, as can be seen from their reports, has proceeded without substantially benefiting from results obtained elsewhere.

About one fifth of the Urban Mass Transit money has gone into demonstrations. Fifty-eight projects were started from 1961 through June 1967, ranging in size and nature from an attempt to use transit passes (\$14,433) to the operation and evaluation of an over water air cushion vehicle (over a million dollars) to engineering and design studies of tracks and rail equipment for the San Francisco Bay Area Rapid Transit District (10,529,000\$, including supplemental costs).⁴⁰ And again, since so many projects have been running concurrently, it would have been difficult to develop, let alone use, the findings of one demonstration for the design of another - even if it had been directed.

Unfortunately, little information has been developed from the urban transportation demonstrations. Grantees are obliged to prepare quarterly and final reports for the Department of Housing and Urban Development and these can generally be obtained. These documents make interesting reading and the results of the experiments they describe are frequently applicable to a number of cities with similar transportation problems. But, except in rare cases, the information is not interpreted, it is not translated into useful criteria or guidelines for transportation planners elsewhere.

More tragically, much of the data collected cannot - even with additional outside effort - be converted into practical functional relationships between supply and demand. By and large, the demonstrations were not designed to make this possible.⁴¹ They were intended by their sponsors to solve particular local problems, not to test whether, for example, there were perceptible interactions between population density and demand, or between schedule frequency and demand. Since this kind of data which would be required to test such hypotheses was not collected, it is impossible to quantify conclusions. The information derived has been of only limited use in developing future service standards. No general theoretical framework was developed for understanding, predicting and reducing to the smallest number of units of measurement the relationship between changes in service and fares, and changes in ridership.⁴²

It is a hopeful sign, however, that more generally applicable studies of the dependency between the operation of transit service and its demand recently seem to have been funded. Specifically, in March 1967 contracts were signed for the field test of a mathematical model to predict bus ridership and for the development of an information system to facilitate management decisions.⁴³ Results of these new efforts will not be available until the end of 1969.

The reason why little has been learned from the demonstrations is easily adduced. The management of the

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mass transit industry is overwhelmingly concerned with the development of smooth, workable arrangements for running its services and is not particularly interested in complicating its planning by worrying about the interaction between its operations and demands. Interviews indicate that, in some major eastern cities at least, the transit authorities assume that demand is unaffected by operational changes and need not be taken into account when determining routes and schedules.⁴⁴ It is not surprising that this apparent lack of concern of the mass transit authorities is reflected in the demonstrations which they proposed, planned and executed.

Thus although about sixty four million dollars have been spent on mass transit experiments of one sort or another, the results have been minimal: little knowledge so far has been transmitted to the profession. Perhaps as Smerk suggested after his extensive examination of the program, information vital to the fortunes of public transportation in Keokuk or Butte is hidden, for instance, somewhere in the vast study conducted by Massachusetts.⁴⁵ But these and other results cannot be useful unless they are systematically analyzed.

A few studies have explicitly indicated an interest in developing correlations between the supply and demand of transit service. These include those conducted by the Bi-State Transit System of Saint Louis,⁴⁶ the City of Detroit,⁴⁷ and the Southeastern Pennsylvania Transportation Authority of Philadelphia.⁴⁸ This last is most easily considered: its eleven findings are mainly qualitative and

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obvious. The first two are, for example: (1) "Location of in-city destination exerts the principal influence on the choice of rail carrier wherever competitive rail services are available" (You take the line that goes where you want); (2) "Location of in-city destination governs the choice of travel-to-work mode from suburban areas" (People take the line that gets them to work).

The studies for Saint Louis and Detroit are more interesting. The Bi-State report suggests that it should be possible to estimate potential ridership by counting houses and estimating ease of access along a proposed route. Ratios are suggested which do not take income levels or other characteristics into account, but which may be valid if conditions similar to those prevailing in Saint Louis are encountered. They also found that, as in Philadelphia, ridership was drawn from a narrow zone around the transportation route, which they were able to define fairly precisely: about three-quarters of the bus traffic came from within a quarter of a mile and this traffic appears to decrease exponentially with distance. ⁵⁰ The Detroit study attempted "to determine the extent to which passenger usage is affected by the frequency of service on a given line." At first blush, the effects of additional service were dismal: ⁵¹ citywide mileage increases of over 50% increased revenues by less than 10%. But the story is far more complex because increases by line segment, time of day and day of week varied widely. ⁵² In addition, since Detroit's supply of men and equipment was strained to capacity in attempts to meet the special schedules, little or

no slack was available to make up for breakdowns or even to boost service at times of peak demands when such raises would presumably have had the most effect. In any event, system wide averages are not particularly informative and specific modes of operation for identifiable segments of the potential ridership should be identified.

Level of Service: A Theory of Trip Price

Level of service is the sum of all the monetary and non-monetary costs to the passenger of making a trip on a particular mode: that is, his total trip price. It can be broken down into the following elements:

1. Frequency of service: measured by headway, in minutes (interval between buses or trains). The average wait is often assumed to be half the headway; there is some indication, however, that the traveler is also concerned with how long he must wait if he misses a bus, and that this involves a cost beyond that of the simple mean wait. In addition, the actual mean headway may be greater than the scheduled headway.⁵³

Waiting involves two kinds of prices: time prices and discomfort prices. The data involved in this study did not permit separation of these prices. They are two separate components, however, and it should be possible to determine the proportion of price associated with discomfort by providing a waiting environment almost entirely free of such discomforts as cold, wind, rain, heat, standing, etc. - i.e., an enclosed heated shelter with seats.⁵⁴

Future tests to evaluate the discomfort price might include

comparing winter surveys with surveys in May on lines with long headways; studying the effects of having a bus spend its terminal time at a passenger loading point, instead of in a non-revenue area such as a special turn-around loop, etc.

In general, rides demanded per unit time should vary inversely with the headway: as the headway increases, riding should decrease. (Note that increasing the headway means decreasing service, and vice-versa). This general relationship can then be stratified by other service or external variables. (See the headway vs. transit usage equations on page 182).

How long a passenger must wait is also dependent on whether he knows the schedule or not, and whether he is willing to restrict himself to a schedule, if it is infrequent. The issuance by the MTA of public time-tables in 1964, after a lapse of several years, should provide some clue as to how important such information is in the Boston area. (see page 190).

2. Speed of service: measured in miles per hour, or total time compared to some alternative. The important price component in speed is time. However, there are other prices associated with speed, including the discomfort of starting and stopping frequently, the psychological effect of passing by other buses or stations, the improved image of an "express" service, even if it is no faster than the local.

There is little data in Boston on the effects of changes in speed. The operating speed of bus lines in the

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last five years has not changed substantially, nor of rapid transit lines. One exception is the elimination of express services in Medford and Somerville, but the data in these sectors was too garbled to throw light on this problem.⁵⁵ New York has more examples of this sort, due to the elimination of express services on some subway lines, the reduction of running times due to new equipment (in New York, routes are long enough to allow noticeable reductions in running time), and the introduction of special express services.

3. Seats available and number of standees (extent of congestion): measured in passengers per square foot, or passengers per seat, or probability of having to stand. The price components here are the discomfort of standing (varying with the length of ride, number of shifts in speed of vehicle, type of vehicle, weather, age or rider, etc.) and the discomfort of crowding (varying with similar factors, as well as with the type of people one must mingle with).

The time of day will determine in part the passenger's tolerance to crowding. Tolerance is probably higher (i.e., permitting greater crowding) in rush hours than at other times.⁵⁶ Urban dwellers have been trained to expect greater congestion in most forms of travel in the peak hours. However, in the long run this very congestion, on the highway between automobiles, or in public transit vehicles between people, may result in shifts in travel patterns. When no alternative mode of transport to the Central Business District (CBD) offers low

congestion (discomfort) costs in the peak hours, travelers may tend to seek jobs elsewhere, or move within walking distance of their job. Either move lessens congestion costs, but the one based on the lower congestion costs of non-CBD automobile oriented job destinations incurs a considerable external cost to the city. These losses could, in the long run, reflect as prices to the individual urban trip maker.

4. Transfers: measured in total trip time in transfer, or energy expenditure. It is hard to define a suitable measure for this price as it overlaps several others, including time, climbing and walking (which varies according to whether the transfer is across-the-platform, between buses, through stairs and passageways; involves sheltered or unsheltered waits; etc.). In general, the less transfers a trip requires, the more travelers will use the service. Frequency of connecting vehicles will be important.

The change in riding as the result of a transfer will also depend, of course, on whether there is any desire for through service between the points on two different lines to begin with.

5. Walking: measured in energy per unit time, or mean distance from nearest stop. Walking involves effort, time, discomfort, and the prices of these components vary according to the length of the planned trip, the age of the walker, the weather, whether the walk is pleasant or not, etc. This study accepted the assumption that most transit passengers had origins or destinations of $\frac{1}{4}$ mile

or less from the bus stop, and did not investigate the variability of this component.

6. Escalators vs. Stairs: also measured as energy output, or proportional attractiveness of stations with escalators vs. those without. Not much data is available on this matter (not many escalators are in operation at non-CBD stations in most cities). There is also the matter of determining the difference between having an escalator at either the origin or the destination point, or at both, to the passenger.

7. Knowledge: the amount one knows about a particular service or travel route influences his decision to use it. Many people will avoid the most direct route to a given point because a less direct route is more familiar to them. When information can also avoid discomfort prices such as waiting (schedule information), unnecessary transfers (route information), etc., it becomes an important component of total price. But measuring it is something else. There are a number of variables involved. Perhaps per cent of operating budget devoted to public relations; but this is not a price from the rider's viewpoint.

8. Amenity: measured on a sliding point scale (not developed on the basis of the data examined in this study) using the following variables:

- a. Orderliness vs. Messiness
- b. Colorful vs. Drab
- c. Clean vs. Dirty (inside, outside, tunnel, windows)
- d. Expensive look vs. Cheap look
- e. Courteous vs. Rude drivers
- f. Decibel level of noise
- g. Foot-Candle power of lighting
- h. Well Ventilated vs. Stuffy
- i. Well heated vs. Cold

- j. Air Conditioned vs. Hot and Humid
- k. Smooth vs Jerky ride
- l. Underground vs. above ground right-of-way

This is not intended to be an exhaustive list.

The development of such a scale is a major task in itself. Some simple improvements in amenity such as new cars are discussed later.⁵⁷ But it was not possible to separate the various affective elements involved, as well as time savings, in the case of new equipment.

9. Direct price: measured in monetary price, fare, or cents per mile. The effect of price will vary with distance traveled, thus the latter criterion is preferred. Fares and parking fees are the two basic monetary prices to the traveler in urban transit.

The above descriptions of trip prices were classified by changes in service from the operating point of view (speed, headway, etc.). Each was seen to have one or more total trip costs components, which fell into the following categories:

1. Time - total time of the trip, and time spent waiting, walking and transferring.

2. Discomfort - of walking, waiting, transferring; exposure to weather, physical effort (level, climbing or descending; psychological effect), psychological effects of stopping, discomfort of standing or crowding, of dirt and noise; aesthetic, psychological and status appeal; uncertainty (tension, waiting, safety) and inconvenience, etc.

3. Monetary Price. Jason Fane⁵⁸ has developed a set of computer programs translating time and comfort - what he

calls "non-money costs" - into economic terms, using dollars and cents as the common unit of measurement. The premise of Fane's work, and of this study, is that modal choice is essentially consumer choice in a competitive market, thus falling under the laws of economics. The marginal utility of the various determinants of modal choice is traded off to achieve an optimum for each consumer.

If the actual economic values influencing modal choice by consumers making travel decisions could be accurately quantified and stratified by controlled empirical observation, it would be possible to make substantially accurate predictions using this approach. By translating all variables into a single unit of measure, our understanding of modal choice in urban transportation would be greatly improved.⁵⁹ This is a formidable requirement, as the marginal utility of each variable varies considerably with the user characteristics. For example, a man of sixty will place a much higher marginal (negative) utility on climbing a flight of stairs than a man of twenty.

The ultimate objective of research in this area is to determine these values, to find out what the various components of trip price are worth to the traveler. This study makes a step in this direction by trying to lend some statistical base to relationships between transit usage and these various prices, subject to the statistical limitations of the data. Not all of the components are reflected in the data, nor are the measuring devices used always the best. But it is a beginning, and establishes

a base from which to pursue the matter further.

Hypotheses

Several hypotheses were formulated in a preliminary effort to extract general conclusions from data gathered by the mass transportation grants, and from such statistics as are otherwise available or could be collected by private initiative. Each hypothesis is described qualitatively and quantitatively and is supported by data for one or several cities. A summary of the hypotheses is to be found at the conclusion of this chapter. It is hoped that these initial findings will lead to further analysis and improved or revised expressions.

Note that each hypothesis is based on a specific set of environmental constraints and refers to the specific qualities of the service change studied. The finding that an increase in service on a route operating at practical capacity (see hypothesis number 1) will result in almost as great an increase in riding is, for example, valid for situations where there is a heavy flow of pedestrian and short-distance movement, and for the range of capacity increases observed (28 to 75 percent). Going outside the range of the observations or combining the quantitative statements for two or more hypotheses will not necessarily yield accurate results.

#1: Increasing service at times of peak demand leads to high increases in ridership.

Specifically, it appears that when a transit line of

the type observed (operating on a principal artery with considerable short-distance movement) is operating at "practical capacity" (defined below), any given percent increase in service defined in terms of capacity, C (%), yields an almost equal percent increase in the number of people carried, Y (%): $Y = 0.75C + 0.07$ (see fig. 3 and table 3).

Thus a 100% increase in practical capacity would yield an 82% increase in passengers. Note, however, that the largest increase in capacity examined was 75%. Clearly this is not an indefinite phenomenon, as there is a limit to the demand.

Practical capacity, in this context, was operationally defined as the average number of passengers carried per vehicle at the peak point during the crowded rush hours, on the above described type of route. This is on the average always less than total capacity, simply because of irregular arrivals and loading of passengers.

It is interesting to note that a similar pattern, with seats being the measure of capacity, was observed on both commuter railroads and rapid transit lines. In the Boston area, "The addition of a single car to a crowded train almost immediately has produced increases in travel which have absorbed the additional space."⁶³ Table 4 shows the experience in the Philadelphia area; table 5 shows the results of a similar improvement in New York on a rapid transit line.

Table 3

Increase in Ridership as More Service is Provided
on Congested Routes

Location	Direction	Vehicles		Passengers		C	Y
		Before	After*	Before	After*	%	%
Detroit ⁶⁰	Inbound	51	78	1600	2400	55	50
	Outbound	55	88	2570	4242	60	65
Cambridge ⁶¹ (Mass. Ave.)	To Boston	4	6	200	270	50	35
	To Boston	4	7	200	315	75	57
	To Harvard	8	12	400	570	50	43
Boston ⁶²	No. Station	16	21	1030	1352	28	32

* The Mass. Avenue data represents observations on different days under the same scheduled headway.

Figure 3

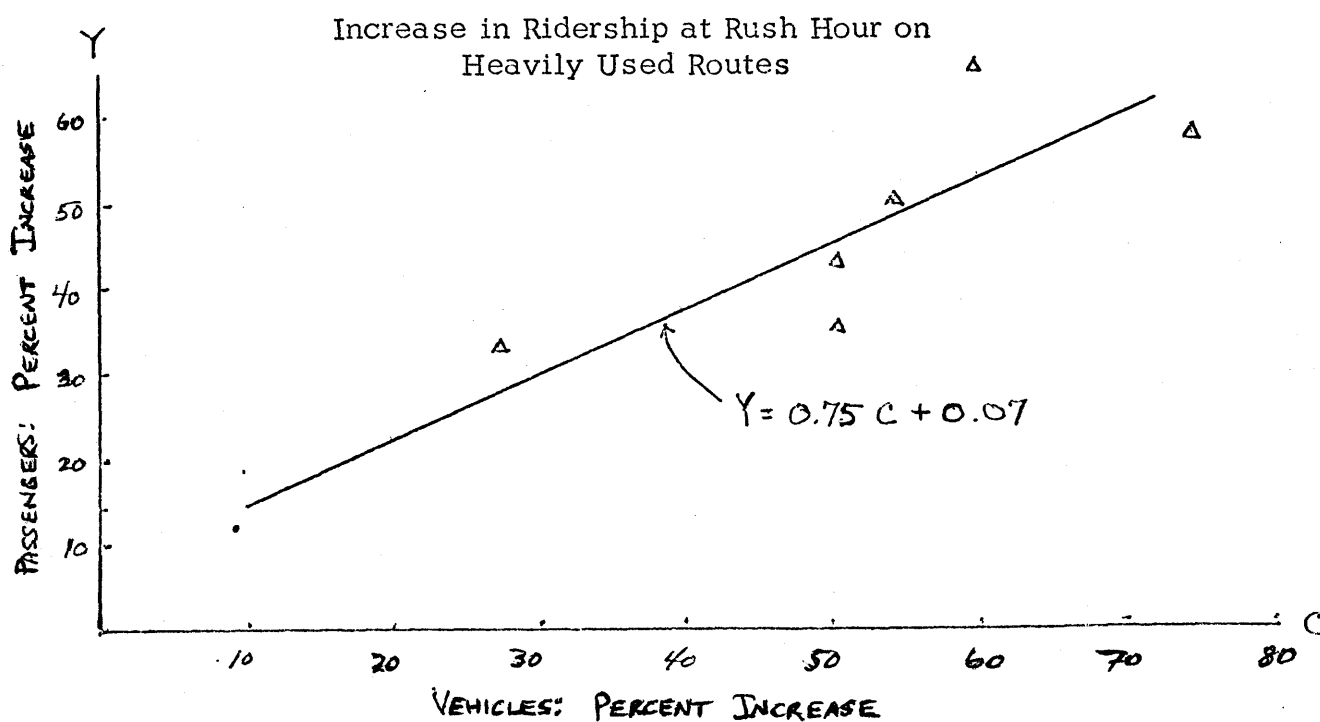


TABLE 4

Increase in Ridership on Commuter Rail lines as
More Seats* are Provided

<u>Location</u>		<u>Seats</u>		<u>Passengers</u>		<u>C</u>	<u>Y</u>
		<u>Before</u>	<u>After</u>	<u>Before</u>	<u>After</u>	<u>%</u>	<u>%</u>
Operation Penn-Hatboro	64 Inbound	3481	4623	3330	4737	32.8	42.3
	Outbound	3552	4378	3000	4334	23.3	44.5
Operation Levittown	64 Inbound	1493	2150	1328	2590	44	95
	Outbound	1200	2000	1252	2204	66.7	76.6

*Through increasing the number and the length of the trains.

TABLE 5

Increase in Ridership on Rapid Transit line as
More Seats are Provided

<u>Location</u>		<u>Seats</u>		<u>Passengers</u>		<u>C</u>	<u>Y</u>
	<u>Direction</u>	<u>Before</u>	<u>After</u>	<u>Before</u>	<u>After</u>	<u>%</u>	<u>%</u>
IRT Broadway 225-242 Sts.	68 Inbound	4400	8800	5445	9870	100	81.5

This correlation between ridership and service at rush hours has important policy implications for the designers of urban systems. A definite possibility exists that it may be possible to alleviate peak traffic congestions at the expense of paying for more men and equipment for the rush hours alone. The proportions of this tradeoff between larger municipal benefits and the convenience of more balanced transit operations are not clear. At present the issue is probably only considered summarily since the decisions lie with the transit operators who may presumably suboptimize their own operations. Yet the question deserves to be explored: public resources may in fact be better spent on the operation of rush hour services than for the provision of highway capacity to service rush hour automobile traffic.

The above hypothesis also suggests that increasing the reliability of service on heavily used lines by more evenly spaced arrivals of vehicles (eliminating "bunching" of buses, for example) will produce additional riding. Potential passengers who now walk or take other modes when no vehicle is in sight (or when they consider it unlikely, from past experience, that one will soon come) would most likely be the main source of such additional riding. The second set of data (from Cambridge) in table 3, illustrates this kind of situation. Running time on this route was reduced in the Spring of 1966, causing a less reliable service and hence greater fluctuation of headway and load. Daily revenue tabulations obtained from the MBTA accounting department confirm the attendant loss. Daily average revenue passengers for the first two weeks after the change dropped from 27,643 to 26,524. Since this was a period of normally heavy riding (Easter shopping and public school vacation, just prior to university vacations) on this line, the real loss was probably nearer 1500 passengers per day.⁶⁵

#2. The installation of through service to rapid transit stations or major activity areas leads to significant increases in ridership. In particular, this change increases demand for bus service about 90% during the mid-day off-peak hours (10:00 A.M. to 2:00 P.M.) and approximately 30% during the rush hours (7:00 A.M. to 9:00 A.M. and 4:00 A.M. to 6:00 P.M.).²⁸ As indicated before, rush hour traffic is more inelastic than off-peak traffic.

These results were obtained by examination of the records of the Massachusetts Bay Transportation Authority on head counts at peak load points both before and after through service was provided. The analysis examined the ratio, R , of the number of passengers carried when there was no transfer point along the line (i.e., through service) to the number carried when there was. The hypothesis that the elimination of transfer points increased riding was accepted at the 95% level using one-sided t-tests (table 6). This acceptance is conservative because the increase occurred while ridership over the system as a whole had decreased, due to a fare increase.

Table 6

Increase in Ridership due to the Elimination
of Transfer Points

<u>MBTA Route Numbers</u>	<u>Ratio of Traffic after transfer elimination (1961 - 1962) to Traffic Before (1960-1961)</u>	
	<u>Mid-day (10 A.M.-2:00 P.M.</u>	<u>Rush (7-9.A.M., 4-6:00 P.M.</u>
54	3.10	1.66
8 and 13	2.20	1.40
51	2.00	1.33
35, 37, and 50	1.40	1.20
100, 103 and 108*	1.66	1.22
106, 107 and 108**	1.50	1.30
97 and 99	1.40	1.12
96	1.75	1.12
Mean	1.88	1.29
Standard Deviation	0.57	0.17

* @ Wellington Square

** @ Malden Square

The results agree with an analysis of the effects of providing through service to Manhattan on three subway lines in Brooklyn and the Bronx (New York City) formerly operated as shuttles.⁶⁷ Twenty-four hour turnstile registrations on a typical weekday changed by + 125%, + 19% and - 22% respectively between 1951 and 1961.⁶⁸ The trend on three control lines in this same period was - 36%, - 46% and - 51% respectively.⁶⁹

The policy implication of this analysis seems reasonably clear: transit operation should be designed to permit direct service through interchanges for trip paths where increases in volume could be sufficient to overcome additional costs, if any. Specific decisions would naturally rest upon explicit analyses of projected passenger volumes and costs.⁷⁰

#3. Ridership is directly related to frequency of service. In particular, expressions relating passengers per thousand inhabitants, P , and the frequency of service expressed in terms of headway between scheduled vehicles H , were derived by cross-sectional analysis of data for metropolitan Boston. The trends deduced were later confirmed by a longitudinal analysis for the same area (fig. 4).

The behavior of different groups traveling for different purposes at different times was explicitly recognized in the analysis. The data was disaggregated by time periods (mid-day, rush hour, and Saturday mid-day) which were taken as proxies for different activities, and

also by the destination (to a feeder station, through a feeder station to a shopping area, and to the central business district).⁷¹

Seventy-one lines were considered in total and the sample size for each distinct category ranged from twelve to thirty-six. Head counts of Metropolitan Transit Authority passengers for 1960 at the station or shopping center nodes⁷² were divided by the population of the service areas as derived from block data of the 1960 census⁷³ to obtain an estimate of P, the passengers per 1000 served. The service area in this context is as defined by the St. Louis study (see p. 146): the zone within a quarter mile of each line⁷⁴ (see table 8). This data was subjected to a least-squares linear regression analysis and the results are as shown in Table 7.

The principal features of this analysis can be illustrated by aggregate expressions for the relation between ridership and schedule frequency:

$$\begin{array}{ll} P = 117 - 3.8H & \text{Rush hour} \\ P = 100 - 2.7H & \text{Saturday mid-day} \\ P = 67 - 1.7H & \text{Mid-day in week} \end{array}$$

In these equations, demand for public transportation is highest at rush hour when it also appears to be most sensitive to the frequency of service. Similar conclusions can be extracted by looking at the different kinds of service. Qualitatively the results agree with what one might expect. Quantitatively they are rather interesting.

Table 7

Passengers per Thousand Served, P ; as
a Function of Headway, H ; Activity;
and Type of Service (Boston, 1960)

Activity	Service Type	Regression Equation	R^2	Sample Size
Midday (10:00 AM-2:00 PM)	Feeder	$P = 51.5 - 1.16 H$	0.72	32
	Shopping	$P = 80.7 - 2.18 H$	0.89	20
	CBD	$P = 80.0 - 2.10 H$	0.90	16
Rush (4:00 to 6:00 PM)	Feeder	$P = 96.7 - 1.771 H$	0.58	32
	Shopping	$P = 141 - 6.82 H$	0.88	23
	CBD	$P = 121 - 3.73 H$	0.84	16
Saturday (10:00 AM-2:00 PM)	Feeder	$P = 87.7 - 2.66 H$	0.81	24
	Shopping	$P = 103 - 2.73 H$	0.97	12
	CBD	$P = 120 - 2.62 H$	0.79	13
Sunday (12:00 Noon- 4:00 PM)	Feeder	$P = 54.9 - 1.435 H$	1.00	36

Table 8

Distance Walked to Bus Stop, non-CBD

BOSTON

	<u>Cumulative # people</u>	<u>%</u>	
1 block or less	2500 (2550)	51	
3 blocks or less	4300	86	Sample 756 expanded to 5000
5 blocks or less	4650	93	

Source: p.98, Final MTC report

CHATTANOOGA

1 block	11,742	68%
2 blocks	3,029	85%
3 blocks	1,704	95%
4 blocks	479	98%
5 blocks	181	99%
6 blocks	137	100%

Source: p.10, Hwy Rsch Bd Bulletin 326

Lounsbury + Wynne

CHICAGO

RAND data from Chicago Area Transportation Study tapes show average walk = 2 to 3 blocks. This is longer for high speed facilities.

Source: Meyer, Kain and Wohl, The Urban Transportation Problem, Harvard University Press, Cambridge, Mass., 1965, Chapter 8 footnote 5.

Correlations with observations in other cities, both large and small, are quite reasonable. In Memphis, for example, it was found that about two to five percent of the residents of an area used the bus when headways of between twenty and thirty minutes were scheduled.⁷⁵ This is well within the range suggested by the analysis. Likewise, in Saint Louis, limited express bus operation (eight buses inbound 6:30 to 10:00 A.M., eight buses outbound 2:30 to 6:00 P.M.) on several routes produced 5 to 26 passengers one-way per 1000 population served in segments with no competition from local routes.⁷⁶

The analysis also agrees with the results of a longitudinal analysis conducted using Boston data from the years 1960 to 1963.⁷⁷ Proceeding in a manner similar to that described previously, the following expressions were obtained:

P = 95 - 5.3T	Mid-day, no change in service
P = 100 - 13.1T	Mid-day, change in service
P = 98 - 3.5T	Rush hour, no change in service
P = 100 - 7.1T	Rush hour, change in service

where P = passengers as a percentage of the original time period and T = the time period in years.

Notice that the slopes of both pairs of equations are greater where changes in service were made.

A graphical representation of the degree of overlap of the confidence intervals of the equation pairs is shown in figure 4. For the Rush period, the "no-change" interval almost completely contains the "changes" interval, while for Mid-day, there is a large portion of each interval not held in common. This would seem to indicate that the service changes have a more pronounced effect on Mid-day usage than on Rush usage.

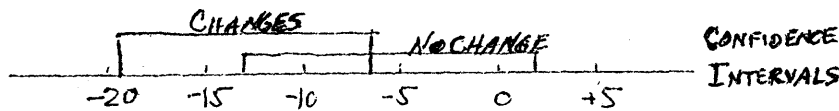
It is, however, difficult to isolate homogeneous samples for longitudinal analysis. In the above set, only two lines and only three years data gives a set of only six points, four of which occur after the particular service change. Since the data fails to allow enough points to determine a line prior to the service change, the precise effect on usage after the change is virtually impossible to determine. In addition, although the control lines experienced no change in headway, one was changed from a streetcar (through to North Station) to a bus operation (terminal at the edge of the CBD),⁷⁸ and another parallels a rapid transit line.⁷⁹

A further corroboration of this hypothesis is worth⁸⁰ noting. A cross-sectional sample of average Sunday revenue was taken for eight bus lines operating from Harvard and Central Square stations in Cambridge and Forest Hills Station in Boston.⁸¹ All except one have no competing transit service on Sundays, do not parallel rapid transit lines, and serve areas of similar income and automobile ownership.⁸²

FIGURE 4
LONGITUDINAL ANALYSIS
VALUES OF Δ PASSENGERS / Δ TIME IN YEARS

MID-DAY

NO CHANGES -12.8 TO $+2.2$
 CHANGES
 (IN SERVICE) -19.6 TO -6.6



RUSH HOUR

NO CHANGES -9.0 TO $+2.0$
 CHANGES -9.2 TO -5.0

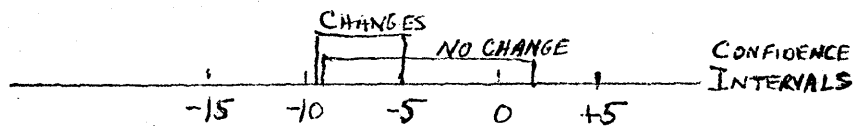
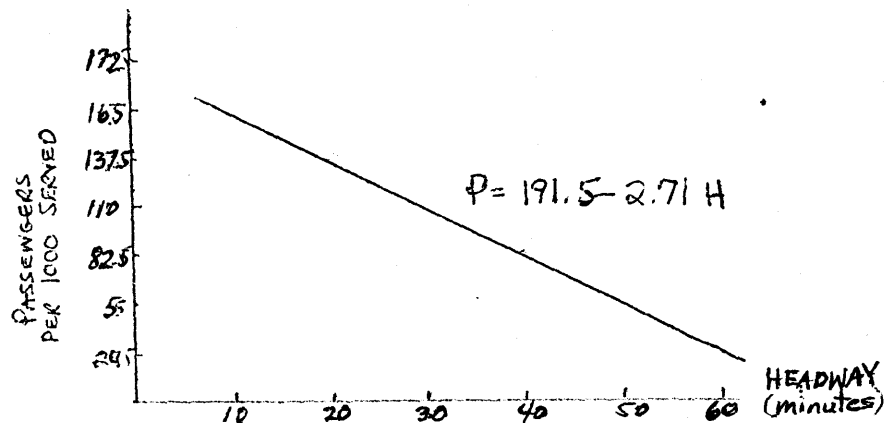


FIGURE 5
RELATIONSHIP OF REVENUE TO HEADWAY ON EIGHT LINES, SUNDAY



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A well-fitted regression line was obtained with the equation $P = 191.5 - 2.71 H$. On September 10, 1967, the Headway on one of these lines (#32) was decreased from 35 to 20 minutes from 12:00 noon to 8:00 P.M. According to the regression, revenue should have increased 42%. MBTA revenue figures show an increase in the first three months of 23% over the previous spring; as of April 1968, the increase appears to be about 33%. The use of cross-sectional analysis in estimating changes over time thus appears to have some validity. (see figure 5)

Several other hypotheses for which no statistical tests were performed are outlined below. They are included because of their importance in both affecting the outcome of choices by management as well as the choice of alternatives; and because of the interesting data or research presented.

4. Congestion and discomfort have significant negative prices to the traveler. C. D. Foster proposes a useful method of measuring this effect. He notes that in London several routes offer the passenger a choice of express or local service in peak hours with a much higher probability of obtaining seats on the local service. He postulates that the number of passengers choosing the slower service are a clue to the value placed on having a seat. He suggests the marginal valuation of the convenience of getting a seat, per mile, is: $C = \frac{(xV)y}{SA}$, where x = the time saved on the express in fractions of an

hour, V = the marginal valuation of time, per hour, y = the percentage of passengers choosing the slower train, S = the length of the trip in miles, and A = the percentage difference between the probability of getting a seat on the fast and the slow train.

There are several similar situations in New York. In a number of cases, passengers actually ride reverse direction one or more stops to the terminal in order to obtain a seat.⁸⁸ Where passengers have an opportunity of transferring to an express and standing or remaining in a local, seated, there are never any seats left on the local when it leaves.⁸⁹ This would imply that for $A=100\%$, i.e. $100-0$, $y = 100\%$. In this case, $C = \frac{(xV)}{S}$. Using the Lexington Avenue line from 125th Street to Grand Central as an example, the appropriate values of x (4 minutes, or $1/15$ hour),⁹⁰ V (\$2.40/hour, using Lisco's mean),³⁸ and S (4 miles)⁹¹ give a value of 4¢ per mile for C . It can easily be seen that this also works out to 4¢ a minute as well; the value of C per minute may be more representative of the passenger's decision criterion than that of C per mile. Similar calculations for the non-rush hour, with $A = 100-50$, i.e. 50% and $y = 25\%$, yield a value of 2¢ a minute; this probably relates to the fact that standing in a train in the rush hour is considerably more uncomfortable than standing in the non-rush hour, when there is room to breathe.

The significance of this hypothesis to policy making is that passengers should be willing to pay a higher fare in order to get a seat. This means that premium fare express bus services might be used in the peak hour in New

York to reduce the load on rapid transit lines, and not increase the deficit. The actual fare collected on such a service would be reduced by the fares lost on the subway line; but for a 20 or 30 minute ride, even a longer trip in time by bus would allow a net revenue of 40 or 50¢⁹² a passenger.

The high value of discomfort may be an important reason for the congestion on urban highways; the institution of guaranteed-seat premium fare services may well alleviate this problem as well.

5. New equipment appears to produce a gain of between 7% and 11% in patronage. Specifically, IRT lines in New York receiving new equipment from 1961-64 experienced increases in riding of up to 9%⁹³. In Boston the difference between the system trend and the trend on the Harvard to Ashmont line in 1962-63, when new cars were delivered, was 7% on weekdays and Saturdays, and 8% on Sundays⁹⁴. In Miami, system revenue rose 11% from 1963 to 1966, a gain of over four million passengers. The management attributes this gain to the introduction of new air-conditioned buses; revenue was still climbing in 1967⁹⁵. Without even considering lower operating costs, a fare of only 15¢ per added passenger would be enough to pay the cost of the buses over twelve years⁹⁶.

The implications for management with regard to both replacement policies and air-conditioning are that it may well pay to upgrade the rolling stock before it is worn out, and to purchase air-conditioned equipment⁹⁷, even if the system itself is paying the capital costs.

6. Knowledge of scheduled departure times can increase patronage on infrequently run routes by 10%. This was the experience in Boston, when the issuance of public timetables resulted in a gain of 5% in average weekday revenues on lines with 15 minute or longer headways in the rush hour, as opposed to a drop in riding on the rest of the system of 5%.⁹⁸ Similar patterns were observed in weekend revenues.

Variation of Demand

The demand for transit services varies widely as the result of a number of external factors. Both in analyzing the results of changes in service, and in applying a consistent set of objectives to service planning, these variations have been accounted for to the extent possible in this thesis. They are described below to illustrate the problems involved and give perspective to the interpretation of such data.

Figure 1 in chapter two shows the variation of revenue by day, Monday to Friday, in 1960 on the Boston system. Tables 9 and 10 in this chapter show how the seasons and the weather can affect patronage. Table 11 shows the difference between normal and summer enrollment at the principal colleges and universities in the Boston area. The variation shown in these tables is rather modest compared with other influences: late-store openings can double peak-load volumes in the evening hours⁹⁹ (and in New York, with only one such night a week, the continuous late hours during the Christmas shopping season bring the number of such nights to 25% of all weekday

Table 9

Monthly Variation in Usage of Transit in Boston
Average Weekday MBTA Revenues by Month, 1960.

<u>Month</u>	<u>Average Weekday Revenue</u>	<u>as % of Annual Average</u>
January	\$119,369	102
February	117,280	100
March	123,263	105
April	120,343	103
May	119,214	102
June	116,985	100
July	104,262	90
August	103,877	90
September	111,898	96
October	116,229	99
November	120,062	103
December	132,279	113
Annual	117,088	

Note: Holidays falling on weekdays were omitted in computing the averages.

Source: MBTA (Massachusetts Bay Transportation Authority) Revenue Department, system revenue by day (the Revenue Department has no official list of monthly or seasonal variation in riding)

Table 10

Effect of Weather on Transit Usage in Boston
 Selected Weekday MBTA Revenues compared to Monthly Average
 1960

<u>All days over .66 inches of rain</u>			
<u>Date</u>	<u>Inches</u>	<u>000 \$ Revenue</u>	<u>Average Revenue for Month(\$000)</u>
1/28	.86	106.5	119.4
2/19	1.33	114.8	117.3
2/26	1.34	116.4	117.3
4/5	1.38	114.8	120.3
5.24	1.02	108.4	119.2
7/14	2.05	92.0	104.3
8/10	0.67	96.3	103.9
9/12	2.95 ^a	62.9 ^a	111.9
9/20	2.13	104.1	111.9
* --- 10/20	.94	112.3	116.2
11/1	1.07	113.6	120.1
12/16	1.81	142.7	132.3
12/21	1.18	129.3	132.3
* 10/24	1.14	110.2	116.2

All days over 6 inches of snow

3/4	19.8	67.8	123.3
12/12	13.0	65.8.	132.3

All days temperature over 90°

6/27	.	.	.	.	.	113.7	.	.	.	117.0
6/28	.	.	.	.	.	113.5	.	.	.	117.0
7/12	.	.	.	.	.	101.0	.	.	.	104.2
7/13	.	.	.	.	.	97.9	.	.	.	104.2
8/29	.	.	.	.	.	99.5	.	.	.	103.9
9/1	.	.	.	.	.	103.2	.	.	.	111.9
9/8	.	.	.	.	.	107.5	.	.	.	111.9

Source: Monthly U.S. Weather Bureau Climatological
 Reports and Massachusetts Bay Transit Author-
 ity Revenue Audits.

Table 11

Summer enrollment at Colleges and Universities in the Boston area vs. Spring or Winter Enrollment, 1962.

<u>Educational Institution</u>	<u>Normal Enrollment</u>	<u>Summer</u>
Boston University	19,620	8260
Northeastern University	19,705	1910
Harvard University and College, and Radcliffe	13,515	4255
Boston College	8,900	2760
Mass. Inst. of Technology	6,695	1750
Tufts University	4,585	930
Boston State Teachers College	1,765	860
Brandeis University	1,750	
Wellesley College	1,735	
Simmons College	1,595	300
Emmanuel College	1,145	150
Babson, Emerson, Newton, Sacred, Conservatory, Wheelock, Lesley, College of Art	4,075	185
Total	85,085	21,360

Source: American College Guide

nights); turnstile registrations in New York from Midnight¹⁰⁰ to 4:00 A.M. double on Saturday and Sunday mornings; and an event at North Station in Boston can triple riding on¹⁰¹ the streetcar system at night.

Because of these variations, information should be collected and schedule specifications structured for "homogeneous time periods." An example of such a classification for weekdays on New York's rapid transit lines is shown in table 12.

Uncertainty of Demand Data

Because of the large number of variables affecting the demand for transit service, several observations of the response to a particular kind of service change may yield varying changes in demand. It may be desired to know the probability of another change of this kind creating changes in demand over the range of the previous observations, rather than simply calculating the statistical mean or best fitted regression line.

There are two simple ways of expressing these probabilities. One is to multiply each group mean by its respective probability and to sum the results. The groups referred to are arbitrary divisions of a total sample of data, and the probabilities are simply the proportion of times the data falls in each group. For example, if a given kind of service change has been observed twenty times, and has resulted in an 11-15% increase in revenue twice, a 6 to 10% increase six times, a 1-5% increase eight times, a -3% decrease once, and no change at all three times, then the $P(-1 \text{ to } -5\%) = .05$,

Table 12

Homogeneous Time Period Classification, New York, Weekdays

<u>Period</u>	<u>Hours</u>	<u>Further difference between</u>
Early A.M.	5-6:30	
A.M. Fringe rush	6:30-7:30 and 9:00-10:00 A	
A.M. Rush	7:30-9:00 A	
Mid-day	10:00A-3:00P	Christmas shopping per.& other
P.M. Fringe rush	3-4P and 6-7P	Christmas shopping per., Spec. early dismissal days and all other
P.M. rush	4-6	"
Early evening	7-10 P.M.	Stores open vs. closed
Late evening	10P-1:00 A.M.	Friday & Holidays vs. others
"Owl"	1-5 A.M.	

For some or all of these, additional differentiation must be done to account for:

- school in session or out
- summer beach and recreational travel
- summer weekday travel (lighter)
- snowstorm travel (heavier for first few days)
- inclement weather travel (lighter in mid-day)
- special holidays (Jewish, Bank, etc.)
- special events (parades, etc.)

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$P(0 \text{ change}) = .15$, etc. The total of the probabilities times the group means is 4.75%, called the expected value of the revenue increase for a 21st change.¹⁰²

This expected value, however, is simply the mean and does not relate the fashion in which the observations vary. For the purpose of choosing among alternatives, it would be more desirable to present the probabilities in a table.

Other Sources of Demand Data

The hypotheses presented in the previous pages were all tested with data gathered by transit systems in the form of peak load counts or revenue tabulations. Such data does not, however, reveal anything about the origins and destinations of the demand, nor does it indicate the amount of untapped demand. It is clear, however, that the strength of a route lies in the extent to which it serves the principal destinations of its prospective users. This quality has been termed "route generality (the range of possible destinations which could be reached by transit from some given origin)."¹⁰³ While no statistical measures of this parameter were developed for this thesis, there are two good sources of data from which it could be measured.

Several transit systems have in recent years taken on-board postcard surveys. In Boston,¹⁰⁴ Washington, D.C.,¹⁰⁵ and San Francisco,¹⁰⁶ cards were handed out to riders on a sample of inbound buses on all transit lines. Riders filled in information on origin and destination of the trip, modes used to and from the vehicle they were handed the

card on, time of trip, purpose of trip, stops on and off,
 and basic socio-economic data (such as automobile ownership.)¹⁰⁷
 Cards were either handed in or mailed in, coded and tabulated
 by line. The results gave a picture of the travel pattern
 of existing passengers.¹⁰⁸

One of the suprising results of these surveys is the
 diverse destinations of the transit riders on the bus lines.
 Central Business District destinations were often in the
 minority.¹⁰⁹ Such data might suggest that no clear advantage
 would be served in running all vehicles through to the Cent-
 ral Business District, as opposed to some other locus of trip
 destinations.

The absence of certain destinations, large transfer
 volumes, etc. are discussed in Chapter 7.

Home Interview surveys cover trips by all modes, as
 opposed to postcard surveys which reveal only existing
 transit trips. These surveys are generally coded by zones
 and subzones, unfortunately not always drawn so as to ident-
 ify the effects of either major activities or transit lines
 (the same is often true of the coding of the postcard sur-
 veys). The information relevant to the transit analyst is
 the proportion of trips made by mode between zone pairs. A
 low percentage of trips by transit may often, although not
 always, indicate a potential for better service. It is
 important in analyzing such data that it be grouped accord-
 ing to homogeneous time periods, as discussed earlier (p. 40).
 Care must also be taken to be fully informed of possible
 errors in the coding.¹¹⁰

Future research is suggested to develop statistical measures making use of these data sources. Their use as guidelines for scheduling and route planning is discussed in chapter 7 and illustrated in chapter 8.

A very important piece of data not inferrable from either peak load counts, revenue audits or origin and destination surveys is the percentage of new riders observed on an improved service who are new to the system, as opposed to diverted from other lines; and vice-versa, what percentage of riders lost by reduction in service are lost to the system altogether, as opposed to diverted to other lines. One of the weaknesses of the Demonstration experiments in Boston was that the new lines carried a low proportion of new riders as a percentage of the total riders. A line which diverts riders from other services is not necessarily undesirable, if compensatory reductions can be made in the other services and the passengers are better served. But in order to get a true picture of the net operating contribution of a given change, this information should be obtained.

It is relatively easy to find out the former mode of travel of new riders, through the use of a postcard on-board survey. Seeking the whereabouts of lost riders is harder; home-interviews would be best, although postcard surveys on the services most likely to have picked up the diversion might suffice in many cases.

Continuous monitoring of the percentage of new or lost passengers would not be necessary. In time, a transit

system would be able to develop statistical estimations based on a sampling of service changes. However, it would always be advisable to sample a vehicle or two as a check.

Other surveys of interest might examine the extent to which residents of a given area are aware of the transit service available to them, and their perception of its service characteristics; special movements, as to the theater, etc. on Friday and Saturday nights, and so on. Sample surveys of this sort in a small area might provide fertile material from which to generalize.

Conclusion and Summary

The most important thrust of this chapter has been to develop and test hypotheses on the effect of changes in transit service on demand, as a base for further development of the proposed method of Schedule and Route Planning in later chapters and as a base for future research. After first reviewing previous research on modal split and the effect of transit service on demand, a theoretical framework for the subject was presented. The following hypotheses were then developed:

1. $Y = 0.75C + 0.07$, where Y = percent increase in riders passing a given point, and C = percent increase in practical capacity at that point. For lines serving a high density of short trips on main arteries.

2. $R = 1.88$ rush, 1.29 non-rush, tested and accepted at 95% level using one-sided t-tests; where R = the ratio of the number of passengers using through service to the number counted when a transfer was required.

3. $P = a - bH$ (see table 7 for values of a and b according to homogeneous time period and type of service), where P = passengers per 1000 population living within $\frac{1}{4}$ mile of a route and H = actual headway.

4. $C = \frac{(xV)y}{SA}$, an equation borrowed from the literature and tested on New York data, relating the value of getting a seat (C) to the time saved standing (x), the marginal value of time (V), the percentage of passengers choosing the slower train to get a seat (y), the length of the trip in miles or minutes (S), and the probability of getting a seat (A).

5. New equipment produces gains of from 7 to 11% in patronage.

6. Knowledge of scheduled departure times on infrequently run routes can increase patronage by 10%.

The variation of demand that must be considered in evaluating these hypotheses and any other observations on demand for transit was then illustrated, and a method of handling the resultant uncertainty of the data briefly discussed. Finally, other sources of data on demand that will be used in the development of the proposed method are discussed.

The material developed in this chapter will be applied in chapters 7 and 8.

Footnotes

1. Part of this chapter is contained in a paper presented at the 1968 Transportation Research Forum proceedings in Kansas City, Missouri, and published as "Effect of Operating Policies of Urban Mass Transportation on Demand" (by Richard de Neufville and Alex Friedlander), Massachusetts Institute of Technology, Department of Civil Engineering, Professional Paper P68-9 (Cambridge, Mass., June, 1968). The material on modal split draws on previous research by the author, as do some of the data presented in testing the hypotheses. See Alex Friedlander, The Relationship between Level of Service and Riding in Urban Mass Transit: A Statistical Study, unpubl. research paper (Mass. Inst. of Technology, Department of City and Regional Planning, 1965) and Determination of Optimum Service in Urban Mass Transit, M.S. Thesis (Mass. Inst. of Technology, Department of Civil Engineering, 1965).
2. State of Illinois, Chicago Area Transportation Study, Final Report (Chicago, 1959-1960), Vol. 1, 2.
3. Pittsburgh Area Transportation Study, Study Findings (Pittsburgh, 1961), Vol. 1 and Forecasts and Plans, 1962.
4. Technical Committee for Highway Planning, A Study on Highway Planning for Metropolitan Vancouver, British Columbia (Vancouver, 1958).
5. "The Use of Public Transportation in Urban Areas," Traffic Quarterly, XVI, 4 (October, 1962), 488-498.
6. Michigan State Highway Department, Detroit Metropolitan Area Traffic Study, Parts I and II (Lansing, Michigan, 1955).
7. Greater Boston Economic Study Committee, Economic Base Report No. 7, A Survey of Commuters on the Highland Branch (Boston, 1960), and Chicago Transit Authority, Skokie Swift Progress Report #4 (Chicago, March 1965), p. 9.

8. See Bibliography for selected list of reports on Mass Transportation Demonstration Projects sponsored by the Housing and Home Finance Agency in Boston, Detroit, New York (Tri-State), Philadelphia, St. Louis (Bi-State), and Washington.
9. Minneapolis-St. Paul Transportation Study, The Role of Mass Transit in the Twin Cities (Minn., 1963).
10. "Some Aspects of Future Transportation in Urban Areas," Highway Research Board Bulletin 326; Urban Transportation: Demand and Coordination (1962), 1-31.
11. "Factors Influencing Transit and Automobile Use in Urban Areas," Highway Research Board Bulletin 230; Trip Generation and Urban Freeway Planning (1959), 101-111.
12. "Transportation Usage Study," Highway Research Board Bulletin 203; Travel Characteristics in Urban Areas (1958), 47-51.
13. Parsons, Brinckerhoff, Hall and MacDonald, Southern New Jersey Mass Transportation Survey (New York, 1956).
14. National Capital Region Mass Transportation Survey, 1958: Traffic Engineering Study (New Haven, 1959).
15. Brian V. Martin, F. W. Memmott and A. J. Bone, Principles and Techniques of Predicting Future Travel Demand (Cambridge, Mass., 1961).
16. Penn-Jersey Transportation Study, interim papers, 1962-64 (mimeographed).
17. Thomas B. Deen, William L. Mertz, Neal A. Irwin, Application of a Modal Split Model to Travel Estimates for the Washington Area (Toronto, 1963). See also D. M. Hill for Traffic Research Corporation in Bibliography.
18. Martin J. Fertal, et. al., Urban Transportation Branch, Urban Planning Division, Office of Planning, Bureau of Public Roads, U. S. Department of Commerce, Modal Split: Documentation of Nine Methods for Estimating Transit Usage (Washington, D. C., December 1966).

19. Stanley Leon Warner, Stochastic Choice of Mode in Urban Travel: A Study in Binary Choice (Evanston: Northwestern University Press, 1962), pp. 66 and 76.
20. T. A. Domencich, G. Kraft, and J. P. Valette, "Estimation of Urban Passenger Travel Behavior: An Economic Demand Model," Paper, 47th Annual Meeting of the Highway Research Board, Washington, D. C., January 1968.
21. The survey was conducted by Wilbur Smith and Associates; tabulations of origins and destinations have been made by Alan Voorhees & Associates; Peat, Marwick & Livingston; and the Harvard-M.I.T. Joint Center for Urban Studies, among others.
22. Op. cit., Domencich, et. al., pp. 9-10.
23. The author found this to be true in actual application of both the Traffic Research Corporation model to Queens-Long Island planning predictions in 1965 and the Charles River Associates model to a case study for Boston in connection with a study of the effects of having a zero fare transit service in 1968. While both models gave reasonable projections on an area-wide basis, it was found to be nearly impossible or illogical to apply them to smaller areas.
24. See, for example, William J. Baumol and R. E. Quandt, "The Demand for Abstract Transport Modes: Theory and Measurement," Journal of Regional Science, VI, 2 (1966), 13-26. The application of this model to Northeast Corridor projections is also discussed in R. E. Quandt, "The Construction of Travel Demand Models with Incomplete Data," in Transportation Research Forum, Papers - Seventh Annual Meeting (Oxford, Ind., 1966), pp. 115-123.
25. John F. Curtin, "The Effect of Fares upon Transit Riding," paper, 47th Annual Meeting of the Highway Research Board, Washington, D. C., January 1968 (in Highway Research Record, No. 213).
26. The New York Times, February 22, 1968.
27. Lewis M. Schneider, Marketing Urban Mass Transit (Boston, 1965), p. 77-79; also his Ph.D. thesis, "Management Policy in a Distressed Industry: A Study of Urban Mass Transit," Harvard, 1963.

28. William Lassow, "The Effect of the Fare Increase of July 1966 on the Number of Passengers Carried on the New York City Transit System," Paper, 47th Annual Meeting of the Highway Research Board, Washington, D. C., January, 1968 (in Highway Research Record, no. 213).
29. Lassow, p. 10.
30. New York City Transit Authority, Transit Record, Vol. XLVII, No. 8, August, 1967.
31. Transit Record, op. cit., p. 5. Note that a +4% adjustment is necessary to the 1966 data to account for the strike from January 1-12 of that year.
32. United States Bureau of Public Roads, Federal Laws, Regulations and Other Material Relating to Highways (Washington, D. C., 1966).
33. G. Charlesworth, D. J. Reynolds and J. G. Wardrop, "Road Improvements: Choosing Priorities by a New Formula," Engineering, 1959, 188 (4873), 185-88.
34. A Stochastic Model of Urban Transportation (Evanston, 1963).
35. Transportation and Urban Land (Washington, D. C., 1961).
36. "The Economics of Consumer Choice in Urban Transportation," Automobile Manufacturer's Association, The Dynamics of Urban Transportation (Detroit, 1962), 16.1-16.8.
37. T. C. Thomas, "The Value of Time for Commuting Motorists," Stanford Research Institute Report.
38. Thomas E. Lisco, "The Value of Commuters' Travel Time - A Study in Urban Transportation," Paper, 47th Annual Meeting of the Highway Research Board, Washington, D. C., 1968.
39. W. R. McGrath, "Urban Transportation is an Urban Problem," Traffic Quarterly (July 1967), 307-320.
40. U.S. Department of Housing and Urban Development, "A Summary of Urban Mass Transportation Demonstration Projects" (Washington, D. C., Jan. 1968).

41. For an interesting discussion of this point see W. Hooper, "Why Demonstrate," in "Transportation Demonstrations: Link between Analysis and Decision," Transportation Research Forum, Papers - Sixth Annual Meeting (Oxford, Ind., 1965), pp. 23-31.
42. See Alex Friedlander, Commentary on Mass Transportation in Massachusetts, A Report of the Mass Transportation Commission (Boston, 1964, unpublished report for Massachusetts Department of Public Works) for an analysis of the shortcomings of the demonstrations in Boston.
43. Cited in 40. These studies are being conducted by the State of New York and Kent State University in Ohio.
44. Conducted by the author in New York, Boston and Cleveland with the heads of the Schedule Departments in 1967-68. See Chapter II.
45. See, for example, G. M. Smerk, "Federal Urban Transport Policy: Here - and Where do we go from Here?" Traffic Quarterly, XXI, 1 (Jan. 1967), 29-52.
46. Bi-State Development Agency of the Missouri-Illinois Metropolitan District and Bi-State Transit System, The Radial Express and Suburban Crosstown Bus Rider, United States Dept. of Housing and Urban Development, Mass Transportation Demonstration Project INT-MTD-8, Final Report, p. 5. See also Chapter V, this thesis, p. 184.
47. City of Detroit, Department of Street Railways, Final Report, Grand River Avenue Transit Survey - Detroit, Michigan Demonstration Grant Program (Jan. 15, 1963) (see esp. pp. 4-12).
48. SEPACT II Demonstration Project Commuter Rail System Study, Report 106(D), Mass Transportation Demonstration Project PA-MTD-4 (Philadelphia, Nov. 1966).
49. SEPACT, op. cit., Vol. I, pp. 9-12.
50. See Table 8, p. 183.
51. See Grand River, op. cit., esp. pp. 4 and 5 and Tables II and III.
52. See Table 3, p. 176, this chapter.

53. This is discussed under Actual Running Time and Headway, Chapter VII, pp. 312 ff.
54. The perception of both actual and adequate headway itself may be affected by such factors. See F. W. Doolittle, Cost of Urban Transportation Service (American Electric Railway Assoc., 1916), pp. 196ff.
55. See discussion of data problems later in this chapter.
56. See Doolittle, op. cit., p. 206.
57. See page .
58. "Some Factors Affecting the Cost of Passenger Transportation," S.B. Thesis (Massachusetts Institute of Technology, Cambridge, Mass., Jan. 1964).
59. For another approach to this question, see R. de Neufville, "Toward a Comprehensive Systems Analysis for Transportation Planning: An Urban Example," in Transportation Research Forum, Papers - Eighth Annual Meeting (Oxford, Ind., 1967), pp. 109-127.
60. Data from the Mass Transportation Demonstration Project Report (47) and Detroit Street Railway Department schedules obtained by the author.
61. Data from street observations by the author, 1966-67.
62. Data from Mass Bay Transit Authority files collected in conjunction with Mass Transportation Demonstration Project Mass-MTD-3, July 1964.
63. Commonwealth of Massachusetts, Mass Transportation Commission, Tentative Conclusions, Demonstration Project Mass-MTD-3 Progress Report #5 (Boston, Nov. 22, 1963), p. 13.
64. SEPACT, op. cit.,⁴⁸ "Marketing Report", No. 3, Vol. III, Nov. 30, 1966.
65. Recent observations (July, 1968) in New York showed that on the B-36 bus route to Coney Island Beach on Sunday, operating at practical capacity on an 8-minute headway, 42% of the passengers waiting to board at one stop decided to walk or take a taxi when unable to board the first bus that came by.

66. Obtained by the author through the courtesy of the MBTA Timetable Office.
67. Dyre Avenue, Macdonald-Culver, and Fulton-Liberty subway lines.
68. Turnstile counts courtesy of the New York City Transit Authority.
69. Woodlawn-Jerome, Queens IND and Sea Beach lines.
70. For a discussion of the use of origin and destination data to this end, see pages 237 ff.
71. For a complete presentation of these data, see Alex Friedlander, "The Relationship between Level of Service and Riding in Urban Mass Transit: A Statistical Study," research paper (Mass. Institute of Technology, Dept. of City & Regional Planning, Cambridge, Mass., 1965).
72. Obtained through the courtesy of the MBTA Timetable Office.
73. United States Bureau of the Census: U.S. Census of Housing: 1960. Vol. III, City Blocks, Series HC(3), nos. 180, 182, 183, 190, 191, 196 (U.S. Government Printing Office, Washington, D.C., 1961).
74. Where two routes were spaced less than one-half mile apart, the service area was divided evenly between them. That passengers will, under circumstances of moderately different services, walk to the stop nearest their origin is well documented by R. L. Levis, in a term paper for Massachusetts Institute of Technology course 1.213, "Factors to be Considered When Determining the Travel Resistance of a Mass Transit Line: A Case Study" (Jan. 18, 1967). Mr. Levis found, in a questionnaire with a return rate of 73% (total sample 107 people) that 90% (96 passengers) were minimizing their walk time, rather than their travel or waiting time, in choosing which of three available streetcar-subway services to use. Even on the fastest of the three routes, only one-fourth of the passengers cared that it was the fastest route.
75. Memphis Transit Authority, Mass Transportation Studies in Memphis, Final Report, TENN-MTD-1 (Memphis, March 1965), p. 100ff.

76. Bi-State Transit System and Development Agency, The Radial Express,⁴⁶ p. 5. Based on an assumed 3.3 persons per housing unit in the areas served.
77. "No change" lines 43, 46, 49; "Change" lines 11 and 69 (Watertown streetcar) midday, 11 and 45 rush hour.
78. Line 43, Egleston to Boylston and Stuart.
79. Line 49, Northampton to Washington and Kneeland.
80. From the spring of 1964, courtesy MBTA Accounting Department.
81. Line 70-83, included to capture the effect of 60-Minute Headway.
82. According to the 1960 U.S. Census tract data.
83. $R = .95$.
84. Courtesy MBTA Accounting Department.
85. Part of the difference is probably due to the lack of any publicity or marketing surrounding the change.
86. Calculation of a Consumers' Surplus Rate of Return on the Proposed Victoria Line (Jesus College, Oxford, Great Britain, June 18th, 1962-prepared for the British Ministry of Transport).
87. Ibid., Appendix I, p. 3.
88. For example, Grand Central to Times Square on the Flushing IRT line, or 169th Street to 179th Street on the Queens IND line. The author has observed this, and it is well known to the passengers at these stations. Often at the height of the rush hour trains arriving at these terminals for their peak-direction bound trips arrive with no seats available.
89. Based on numerous observations by the author.
90. Based on New York City Transit Authority schedules.

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91. The interchangeability of the availability of seats with the speed of service was also brought out in the development of the Traffic Research Corporation modal split model for the Queens-Long Island Mass Transit Demonstration Project. The multiple regression model was assigning too few passengers to the Jamaica-BMT subway line, on the basis of time and excess time comparisons; this line was slower and ran less frequently than the parallel Queens-IND line. But it was significantly less crowded. The introduction of a parameter to express the availability of seats was recommended by the author in 1965; the result was a more realistic assignment of passengers to the Jamaica line, as well as several other lines, and a higher correlation ratio.
 92. For example, a subway trip of 21 minutes from Church Avenue, Brooklyn to Rector Street, lower Manhattan, on the BMT Brighton line incurs a discomfort cost of 84¢. If a bus via the Prospect and Gowanus Expressways and the Battery Tunnel took 27 minutes, the average passenger would pay up to 60¢ one-way to get a seat (84¢ less six minutes extra time x 4¢/minute cost of time). The net to the company would be 40¢ per passenger, assuming the passengers all now pay 20¢ to take the subway. Undoubtedly a few automobile users would be attracted too, at a net of 60¢ per passenger.
 93. New York City Transit Authority 24-hour turnstile counts, Woodlawn-Jerome line. Similar experiences, although confined to non-rush hours, were noted on the BMT lines.
 94. MBTA turnstile counts.
 95. Metropolitan, 63, 2 (March-April 1967), 26-27.
 96. Using a Capital Recovery Factor of .11928: see J. R. Meyer, J. F. Kain, M. Wohl, The Urban Transportation Problem (Cambridge, Mass, 1965), p. 178.
 97. For a full discussion of management attitude towards air conditioning, see Lewis Schneider, op. cit.,²⁷ pp. 139-143 and 177-178. It should be noted that in the last year both New York and Boston have made the decision to air condition all new equipment ordered from now on.
 98. Metropolitan Transit Authority Revenue Audits for the Fall of 1963 and Spring of 1964, courtesy of the M.B.T.A. Revenue Accounting Department.

99. For example, peak load point counts at Dekalb Avenue southbound on Friday, January 31, 1964, and Thursday, March 10, 1966, show 2,510 and 4,720 riders respectively from 9:00 to 10:00 PM on the Brighton line.
100. Based on special turnstile counts taken in connection with police saturation program.
101. Based on M.B.T.A. traffic surveys.
102. See, for example, H. W. Alexander, Elements of Mathematical Statistics (New York, 1961), pp. 73-74.
103. Walter Y. Oi and Paul Shuldiner, An Analysis of Urban Travel Demands (Northwestern University, Evanston, 1962), p. 20.
104. In conjunction with the Boston Regional Planning Project surveys conducted in 1963.
105. By the National Capital Transportation Agency in 1966.
106. According to Mr. Joel Miller of A. Voorhees Associates, in an interview in Washington, D. C., April 17, 1968.
107. See, for example, Wilbur Smith and Associates, Boston Regional Planning Project, Coding Manual, Transit Postcard Survey (Boston, 1963-64), I, 10-12.
108. The accuracy of the Boston postcard survey is discussed in Chapter II, footnote three; see also figures 3 and 4 in that chapter.
109. For example, of the 125 inbound trips sampled on line 72, Aberdeen and Huron to Harvard, Cambridge, 22 originated outside of Cambridge. Of the 103 originating inside Cambridge, only 34 were bound for downtown Boston. See also the destination data presented in the example in Chapter VIII.

110. A sample of the original home-interview surveys for Cambridge was examined and note made of the coding and classification. One interesting error noted by the author was the inclusion of all the Harvard Medical School interviews and Massachusetts Institute of Technology Graduate House interviews in the Harvard Square Zone. When an interview sample of a few per cent is being expanded to represent a 100% sample, such errors can become important. It was also noted that interviews were conducted during Spring Vacation or Reading period, resulting in a high number of missed student interviews and an underestimation of trips.
111. Commonwealth of Massachusetts, Mass Transportation Commission, Mass Transportation in Massachusetts, Final Report (Boston, July 1964), p. 99, table 71.

CHAPTER VI
ESTIMATION OF COSTS

CHAPTER VI

Estimation of Costs

The primary purpose of this chapter is twofold: to develop cost functions for use in illustrating the proposed methods of Schedule and Route Planning in later chapters; and to show that the costs of increments in bus or rapid transit service are less than the average accounted cost. A secondary purpose is to demonstrate, to the extent that the data allows, that certain costs vary inversely with the speed of operation. This will enable more accurate evaluation of proposed changes in schedules and routes.

At the same time, methods for determining the exact costs for each category (maintenance, power, etc.) are used which it is hoped can be applied to constantly changing cost data.

The costs relevant to the model, that is, those which would be input into a calculation of NOC (Net Operating Contribution), are the variable cents-per-mile costs summarized at the conclusion. They will be used in chapter eight.

The data will be generalized to derive similar variable labor and mileage costs for bus service in Boston for use in chapter 7. Because of the lack of data on the effects of speed in Boston, the mileage figure will be standard for all the examples in the next chapter.

Unless otherwise noted, all data quoted herein on accounts and costs in New York comes from the New York City Transit Authority Operating Budget for the fiscal year ending June 30, 1967.

In the marginal analysis (see chapter 3) of schedules and routes, the proportion of costs which are variable (as opposed to fixed) will depend 1) on the viewpoint of the decision maker, and 2) on the extent to which the given change affects quasi-fixed costs. In the first case, when the capital investments are paid by the city, they become variable costs only from the community's viewpoint, but not from the transit system's viewpoint. In the latter case, a small percentage change in, for example, mileage, may not affect depreciation rates even when they are imputed to the operating company, while a larger change involving perhaps a doubling of mileage would, even without additional rolling stock, accelerate the depreciation rate.

The specific cost categories that cross these boundaries will be discussed in the course of this section. The important distinction to draw at the outset is that since the model for marginal decision-making is being developed from the transit company's viewpoint, the costs which they must treat as variable will be most rigorously defined. Costs to the community (as well as benefits in later sections) will be evaluated but not given equal importance in the analysis. The relevance of each cost category to various kinds of decisions will also be discussed.

The budgeted and/or real costs of the current fiscal year in New York will be used as a basis for developing and understanding the cost structure of urban mass transit equations. The extensive data on the costs of the publicly owned urban transit operations in New York available to this researcher will provide a basis, a groundwork on which generalizations can be made that will apply to any given transit system. Most systems, large and small, publicly and privately owned, keep their accounts and budgets in a manner similar to that of New York,¹ and incur roughly the same types of costs. Where there is a difference, as in the question of depreciation, the practices and experience of other systems will be called upon.

Since we are dealing with the specific costs of the New York transit system, a physical description of the system and its operations, and a description of its accounting and budgeting methods will first be presented. The major sub-headings of account classifications will then be used to organize the evaluation of which costs are affected by marginal variable (incremental) changes in schedules and routes. After first showing how to compute allowances and fringe benefits into the wage rates, the account classifications will be broken down each in turn to separate those costs which will vary under given conditions. Finally, the specific cost model for New York will be generalized.

Physical Description

The publicly owned and operated transit facilities in New York to which all the cost data in this chapter apply consist of all rapid transit operations (except for the Port Authority Trans-Hudson line), that is, all subway, elevated and open cut operations within the city limits; all Brooklyn and Staten Island bus operations (except for some school service and one line in Brooklyn), bus operations in Queens east of the subway terminals to the city boundaries (including one line to the Bronx), and five bus lines in Manhattan. The remainder of Manhattan and Bronx surface operations (except for two small lines on the lower east side run privately) are operated by a subsidiary called the Manhattan and Bronx Surface Transit Operating Authority. Created as a result of a strike against the then privately-owned company which operated these bus lines in 1962, ownership terms are still not settled in the courts, and cost information is kept separately and not as easily available, although the chief operating officers and executive control for the publicly owned New York City Transit Authority (NYCTA) and the latter group (MaBSTOA) are the same. The bus lines in western Queens are run by several private companies.

The magnitude of the New York operation is in a class all by itself. Annual operating expenses alone, including the police department of close to 3,000 men assigned exclusively to the transit system (mostly the subways), now exceed

\$400,000,000. Capital expenses are paid by the city and, while variously estimated, well exceed \$100,000,000 a year, chiefly for new cars and buses and modernization of the out-dated physical plant which on the oldest lines dates back some sixty years.² Thus the annual cost of the NYCTA operation exceeds half a billion dollars, to which will be added in the near future the infusion of state and federal funds for expansion of rapid transit services through the newly created Metropolitan Transit Authority.

In comparison, the next largest American system, in Chicago, which controls all, not some, of the city's bus operations, spends about \$150,000,000³ a year for operating and equipment replacement expenses. Similar data for London Transport, again with a monopoly on bus operations, are about \$240,000,000.⁴ Additional comparative statistics are listed in table 1.

Table 1

Comparative Statistics for New York,
Chicago and London

	<u>New York</u>	<u>Chicago³</u>	<u>London⁴</u>
Subway cars owned	7,106	1,160	4,124
Track Miles	719.85	210.51	630
Route Miles	236.70	- - -	215
Car Miles per annum	316,000,000	44,349,196	203,094,000
Buses owned	2,345	3,333	8,219
Route miles	554.47	952	5,004
Bus miles per annum	67,326,000	111,067,942	298,485,000

To operate the rapid transit network, New York employs 3,253 motormen, 2,739 conductors, 592 towermen, 1,075 car inspectors, 1,938 car maintainers, 628 car cleaners, 2,721 policemen, 4,209 change clerks, collecting agents and station supervisors, and 1,167 station porters. It buys over two billion kilowatt hours of electricity each year. To operate the buses, 5,082 drivers, 511 dispatchers, 1,072 mechanics are required. Numerous supervisory and administrative personnel knit together the functions of these various employees, while other personnel attend to other functions such as maintaining the right of way.⁵

The rapid transit lines are organized in three divisions called the IRT, BMT, and IND.⁶ Originally, the Interborough Rapid Transit and Brooklyn-Manhattan Transit lines were privately owned, while the more recently built (1930's) Independent lines were city owned. In June 1940, the city bought the BMT and IRT in receivership for \$317,000,000⁷ and subsequently absorbed several private street car, bus and trolley bus systems in the city. The only two portions of original elevated lines left are considered part of the subway system for most purposes (these are the Third Avenue Elevated in the Bronx, which used to run the length of Manhattan, and the Myrtle Avenue elevated in Brooklyn, which used to run over the Brooklyn Bridge to lower Manhattan.) However, many so-called subway lines in the outer parts of the city are actually elevated structures.

Car equipment maintenance crosses division boundaries. A series of inspection shops for scheduled inspections and

routine repairs are located at Pitkin Avenue, Bedford Park, and Jamaica on the IND, 240th Street-White Plains, 239th Street-Broadway, Pelham Bay, East 180th Street, and Jerome Avenue on the IRT, Coney Island and East New York (Brooklyn) on the BMT, and Corona on the Flushing line. (See foldout map in back of thesis).

Major repairs and overhauls are done at two base shops: Coney Island (same location as the inspection shop) for the BMT (and Flushing line), and 207th Street for the IND and IRT. Recently, the new IND-BMT cars, intended for operation through Chrystie Street but now operating on the Queens IND line, have been assigned to Coney Island base and inspection shops; and due to an overload at Jamaica and 207th Street stemming from the increase in age, breakdown and inspections of IND equipment, some older IND cars are now receiving overhauls at Coney Island.

Buses are maintained and garaged at six garages in Brooklyn, two in Queens, one in Staten Island and one in Manhattan. In addition, a base shop at East New York in Brooklyn handles major repairs and overhauls on buses from all four boroughs.

Accounts and Budgets

The New York City Transit Authority keeps track of its costs in two main formats. One is their system of accounts, which is reduced to a monthly published summary called "Transit Record." The other is their annual operating budget, which is a detailed itemization of the expected costs by employee titles and by departments for their fiscal year, which runs from July 1 to June 30.

"Transit Record" normally lists breakdowns of operating revenues, operating expenses and operating statistics (see App. exhibit 1) for the whole system, for the rapid transit and bus components and for the bus divisions by each borough. Data is given for the current month and the expired portion of the fiscal year. Twice a year, a six or twelve month listing of revenue passengers recorded entering each station and using each bus line for the current and previous¹¹ fiscal year is given.

The "Cents per Revenue Car (Bus) Mile" figures are "fully allocated expenses" for each account line divided by the total mileage. This means that the number includes fixed and variable costs incurred by the Authority, and is¹² not used as a basis for decision making, but rather as a measure of performance and a basis for comparison with other systems.

The sub-headings under "Operating Revenues" in the following exhibit are self-explanatory. The next group of sub-headings, under "Operating Expenses and Rentals" comprises the following:

Maintenance of Way and Structures. This is primarily a rapid transit expense, and includes replacement of rails, ties and ballast, roadway and track inspection, repair and inspection of signal and interlocking equipment, repairs of tunnels and structures, third rail, power distribution systems and substations, and repairs (not cleaning) of station and mezzanine structures. In surface operations, the only expense in this category is repairs to shop and garage structures.

Maintenance of equipment. This includes repairs to all rolling stock, revenue or non-revenue (work, garbage collections, revenue collection, etc.) equipment, repairs of shop machinery (as opposed to structure), shop expenses other than structural maintenance (light, power, cleaning), repairs to substation equipment (again, as opposed to structure), and all inspection and servicing costs, labor and material, for all cars and buses.

Power. Only the cost of purchased power (both for operation of cars and for lighting and heating structures and stations) plus the labor to man and operate substations (plus superintendence, a category present in each sub-head) is subsumed here. Maintenance of structures and equipment is allocated to those accounts, rather than power.

Fuel and Lubricants for Buses is a materials account only. The costs of administering the fuels and lubricants are allocated to maintenance of equipment.

Operation of Cars and Buses. Here is accounted the costs of all motormen (road and yard), conductors, bus drivers, station employees (clerks, porters, watchmen, platform conductors), police, car cleaners, towermen and associated material and supervisory expenses. Note that cleaning of cars and stations is considered operations expense, while cleaning of buses is considered maintenance expense.

Injuries and Damages. This includes amounts paid for workmen's compensation and public liability, and the costs of supporting these functions, including the law and medical departments.

General and Miscellaneous. The bulk of the expenses in this sub-heading go towards "fringe" benefits including pension contributions, health plans, social security, and for office clerical work in various departments. The amount listed in Transit Record, however, includes a large credit (about \$31,000,000 for the year ending June 30, 1966) for payment by the city of police costs.

These sub-headings are detailed more specifically in the non-published "Financial and Statistical Report." As an example, the maintenance of way and structures listing from the latter is presented in Exhibit 2, Appendix. Note that to reach the total maintenance of way cost figure for rapid transit listed in Transit Record, the Power structure maintenance costs must be added.

The annual operating budget is divided into two sections. The first, called "personal service", lists the number of employees, basic wage rates, annual budgeted wages and allowances for each civil service or exempt title, by department. The second, labeled "projects," shows the labor and material expenses for various arbitrary functions or projects within each department. The employees listed in the personal service section are allocated to the various projects but without cross-references. To determine how many of each title are included in any given project, it is necessary to refer to supplementary quota sheets known as "Allocation of Employees by Section."

To illustrate the relationship between these three sources, the personal service, project and allocation lists for the Station Department are shown in Exhibits 3, 4, and 5 in the Appendix.

There are 34 budget numbers, most of which refer to specific departments. Ninety-six percent of the expenses are budgeted to nine numbers (see table 2).

Table 2: Major Budget Lines, 1967

No.21	Rapid Transit Transp.	7,846 employees	\$62,124,200
40	Non-Departmental Exp. (SocSec, Pension, Ins. Health Plans)		56,795,600
24	Maintenance of Way	6,153	54,164,000
34	Surface Transp. (Bus)	5,661	49,269,000
25	Car Maintenance	4,097	40,504,000
26	Power	1,072	38,925,000
31	Station	5,615	37,357,000
27	Police	2,796	34,014,850
35	Surface Maintenance	1,530	17,500,000

These nine divisions account for \$390,653,650 of the \$405,317,990 budgeted for the fiscal year ending June 30, 1967. They account for 34,770 of the 36,657 employees. The remaining departments include five with budgets of from \$941,475 to \$2,919,800. These are Revenue (audits and compiled statistics on turnstile registrations and fare box collections), Purchase and Stores (dispenses materials to all departments), Accounting, Law, and Special Inspection (a sort of spy detail assigned to report infractions, misbehavior and errant workers.)

The remaining departments, with budgets ranging from \$55,000 to \$799,960, are: Executive (Commissioner's offices), Budget, Labor Relations, Public Information &

Community Relations, Secretary's, Medical, Personnel, Payroll, Data Processing, Bureau of Reporting and Stenographic Services, Concessions, Office of Superintendent-Employee Services, Safety Bureau, Office of Controller, Office of General Manager, Lost Property, Office of General Superintendent-Surface, Engineering, Employees Assigned to City Departments, and South Brooklyn Railway Company. The last is a small freight railroad running between Coney Island and 36th Street Yards in Brooklyn, at street level along MacDonald Avenue, with accounted expenses of \$259,655 dollars in fiscal 1966, and budgeted expenses of 55,000 in fiscal 1967.

With each annual budget, a small booklet called "Budget Data & Transit Facts" is also prepared. It includes some supplementary data such as annual wage equivalents to hourly rates, salary ranges by years of service, revenues and expenses over a number of years, etc.

Units of Measurement

There are a number of ways to evaluate the costs of a transit service. Each has its use, depending on the purpose of the evaluation. For example, the amount expended per passenger, or revenue collected per mile, are useful comparative measures from one line or division to another to indicate the relative efficiency of the lines.

Since the purpose of this cost analysis is to determine the cost of increments of service deriving from changes in schedules and routes, the unit which measures

the changes in service should be the one by which changes in cost are measured. For computing the labor costs of "conducting transportation," that is, for motormen, conductors, bus drivers, dispatchers, platform and yard help, etc., the schedule requirements in man-hours or simply men are the appropriate unit.

For all other variable costs, the changes in car mileage are both the measure of the service change (for the company) and the basis for cost evaluation. If a cost does not change with the mileage operated, but in some other way, then it will not change with changes in schedules and routes, unless they require changes in capital investment. These assertions are documented in the following pages.

Calculation of Real Wage

The real wage paid to a given employee is not merely his hourly rate on an annual basis. There are two kinds of additional payments which must be computed to find out how much one employee more or less will cost. The first is that class of payment known as "Fringe Benefits." These are included under Miscellaneous expenses in the general accounts, and under Non-Departmental expenses in the budget. This makes it much more difficult to tell how much the manpower for any given function costs. It is necessary to transfer the allocation of these payments to individual wages for our model.

The basic classes of benefits are pensions (New York City Retirement Plan), health and hospital insurance, and

social security. These are all based on the payroll wage, which includes the base wage rate plus allowances for such items as holidays, overtime, sick leave, etc. (see below). Workmen's compensation is computed on the basis of past expenses, having no relation to the wage structure. It will be left to general and miscellaneous expenses.

Pension payments by the NYCTA are 9% of the payroll, and will be assumed to be the same percentage for any bloc¹³ of employees. Health and hospital insurance is \$19.05 per month per employee cost to the NYCTA (slightly higher for Queens and Staten Island bus divisions). Social security paid by the employer is 4.4% up to \$6600 (flat rate of \$290.40 above that) annual wage. Although 7% of the NYCTA employees are not members of social security, it will be assumed that these are nearly all in annual rated titles or other positions not subject to variation in quota with changes in schedules or routes. Workmen's compensation is computed on the basis of past expenses, and will be discussed under the Insurance and Damages category.

Thus for an employee with an annual wage of \$6599 or less, the real wage is $w_1 + w_1 13.4\% + \$228.60$;

For employees with annual wages of \$6600 or more, the real wage is $1.09w_1 + \$519$.

Note that the annual wage w_1 which is expanded by the above formulae is not usually the simple wage rate, but must include the non-uniform allowances (as opposed to benefits) such as holiday allowances, overtime and night differential pay which can be computed from the annual budgeted

expenditures for these allowances per title.

For example, the average hourly rate budgeted for the NYCTA's 2,350 road motormen in regular service during the current fiscal year is \$3,673 (the variation on a given line will be determined by seniority privilege in the semi-annual pick, and can be assumed to distribute as an average over any given schedule or route change). To the annual budget allowance for these employees is added \$2,434,000 or $13\frac{1}{2}\%$ of the base wage for allowances. This increases the base annual wage from \$7,670 to \$8,705. Then, $1.09(8,705) + 519 = \$10,019$ real annual wage per motorman.

Percentage rates for allowances vary among titles, as some are subject to overtime while others are not, etc. For example, a car inspector (see maintenance of equipment) who works five days a week but not holidays will receive no holiday and little night differential allowance. In computing costs for marginal service changes, night differential allowances need not usually be averaged in, since the time of day to which the change applies is known.

In summary, if the % rate on the base wage for allowances is denoted by P in decimals, then the real wage w_1 can be computed from the base wage r_1 in New York for the bulk of employees (whose base wage is \$6600 per year or more) as:

$$w_1 = [(1 + P)r_1] 1.09 + 519.$$

This is how much it actually costs the operating company to hire one more employee at base wage r_1 .

Operation of Cars and Buses

This category refers to the expense of "conducting transportation," and refers to the cost of motormen, conductors and bus drivers. Other operating expenses such as station booth clerks are relatively fixed, varying only if a station or entrance is closed at certain hours; expenses for maintenance, power, etc. are under separate categories.

Vehicle operation is the single most important class of cost which varies with nearly every kind of schedule or route change. The only possible exception would be the elongation or shortening of train length, which would affect mileage but require the same number of road crews. However, even this entails a change in cost, because manpower must be supplied at the terminals to shuttle butts (odd cars) to and from storage tracks or yards, and to assist in coupling and uncoupling the cars.

Most of the costs listed in this category in the New York City Transit Authority's (NYCTA) accounts do not vary with changes in service. Railroad change clerks, station employees (platform men, porters and watchmen), station supplies, signal system operating expense, and other lesser costs remain exactly the same as long as at least some service is provided on a given line. It should be clearly understood that in the case of rapid transit services (for which most of these normally fixed categories apply), no service for part or all of the day is an alternative, and that this does involve changes in some of these costs. The no service alternative will be treated separately. (See page 261)

Towermen and dispatchers may be required or not if changes in service and routing require or omit the use of given interlocking facilities to switch trains from one track to another. The proportional change in cost will be small, however, in comparison with the change in the cost of operating crews.

Supervision is in the nature of a quasi-fixed cost. For substantial changes in service, more or less personnel may be required at terminals and in the main office. The ratio, however, of most quasi-fixed costs to any measure of service both within a given system, and amongst cities, varies so widely - as will be shown shortly - that for all practical purposes, most marginal changes to be considered by an operating company will not affect the supervisory costs, unless there is a specific ratio of supervision to employees criteria adhered to.

The policing function is normally not related so much to schedules and routes as it is to traffic, time of day and geographic area. However, in New York, where a policeman is now assigned to every train and every station for eight hours of the day, the cost of policing the system will at least for those eight hours vary in the same way as the cost of crews for the trains. Because it is thus both significant and obvious, it will play an important role in decision making from the transit management's viewpoint even though the cost is paid by the city.

Motormen, Conductors and Bus Drivers remain as the primary variable costs. The variation of all these costs

is best measured by computing the personnel requirements from schedules and service requirements (see Chapter 2) rather than by a per-mile or per passenger ratio. For the same reasons, however, that makes this true, a performance measure of operating cost per mile or per passenger will say something about the efficiency of the service. These reasons are:

1. The faster a train or bus moves, the more mileage it will traverse in the same time period. Since the crew or driver is paid by time, the same rate of pay will cover that much more mileage. If a bus covers a six mile run in half an hour, the driver-cost-per-mile will be one-half that of a bus covering six miles in an hour. The number of drivers required by the schedule, not the mileage, will yield a uniformly applicable function. At the same time, the driver-cost-per-mile will be lower the faster the service, making it advantageous to trim any excess fat off running times. (Since the total costs will be lower, see chapter 7 p. 244).

There are, in fact, under given working conditions, certain "optimum (from the company's viewpoint) running times which show less cost per car or bus mile than other running times because they involve the maximum coverage in mileage by a crew or driver within the given conditions. For a subway line with road motormen not performing yard work, marginal cost per mile becomes least as running time approaches 34, 42, 58 and 87 minutes; for a bus line, 36, 46, 65 & 93 minutes.

2. A service which tolerates a high percentage of standees will show a much lower operating cost per passenger

than one which provides abundant seats. Here again the cost is determined not by the number of passengers but by the service requirements of the schedule. A low cost per passenger may indicate an efficient service or it may indicate poor quality (high non-monetary price)¹⁵ service.

3. For a given running time, as the time spent in the terminal decreases, the more mileage is covered in the same total crew time and the cost per mile goes down. If changes in terminal time do not enable changes in mileage because of the creation of non-optimal running times, however, than they will not affect the marginal cost per car or bus mile.

4. The number of yard employees required per car being transferred from terminal^{to}yard or from yard to terminal will vary from one terminal to another, depending on how long the distance between terminal and yard, how many cars the platform can accommodate at one time, etc. This variation will affect the marginal cost per car mile. In addition, working rules differ on the three divisions in New York, so that in some cases road crews are available for transferring cars, at no extra cost per car-mile, while in other cases separate yard crews must be added to do so.

5. The longer a train (in New York they vary from 2 to 11 cars) the more mileage it will accumulate on a car-mileage basis, although the crew size will be exactly the same. Thus longer trains will normally show less cost per mile for operation.

It is clear from the above that accurate and fast determination of the actual changes in operating manpower requirements of a given schedule or route change is essential to proper evaluation of all alternatives. Presently it takes about a day for an experienced schedule maker to obtain just a rough idea of the requirements of a given work schedule for one bus or subway line. The application of electronic data processing methods would be most helpful, but for reasons discussed in the chapter on existing methods, attempts thus far to develop a suitable computer program have not been adequate to meet the task; nor will it be attempted in this thesis. Similarly, the rule of thumb methods for estimating requirements described in the above referred chapter are rejected. Given, however, accurate proscription of the crew requirements for each proposed schedule or route change, the following function should be applied to ascertain the operating cost:

Let M , C , D equal the number of motormen, conductors or drivers required, and w_1 their respective wage rates per year (calculated in the manner shown above); then Mw_m equals the annual cost of motormen, etc.

Maintenance of Equipment

The costs in this accounting category are of three types: those associated with the existence of shops and repairs and inspection facilities, including most shop supervision; those based on time; and those based on mileage. Only the last will vary with changes in schedules and routes (unless additional vehicles and therefore more shop or garage

space and time-based work are involved).. It might be assumed at first glance that, since the latter is based on mileage, cost allocation should be easily accomplished. Unfortunately, this is not so.

The employees in the rapid transit shops and bus garages who are responsible for inspecting and repairing equipment are involved in both mileage-based inspections, time-based overhauls, and repair of defective equipment brought in off the road.¹⁸ Overhauls and major repairs are performed at base shops only, but this activity is also both time and mileage based.

This much can be ascertained: all the inspectors and maintainers in the regular garages and shops are engaged in mileage related work. They inspect rolling stock at pre-determined mileage intervals (generally 7500 miles for rapid transit),¹⁹ and handle an additional quota of cars or buses in any given time period brought in off the road for defective performance. The proportion of the number of cars thus brought into the shops that appear for regular inspections can be divided by the actual mileage between inspections (usually somewhat higher than scheduled mileage between inspections)²⁰ to obtain the inspection cost component. This assumes that all three types of inspections and all calls for servicing defective equipment occupy the same man-hours and materials per car, which is obviously not true. However, a more accurate picture is

not possible on the basis of the records currently kept and information available.

The remaining costs for labor and materials in the local shops and garages would thus be imputed to repairs off the road, and might be assumed to be the cause of variation in costs from one shop to another, once differences in the size of the shop, the number of cars or buses assigned and the age and mileage on the cars or buses are all accounted for. Theoretically, this variation in the remainder would be assumed to be due to the average speed of the cars or buses assigned to the shop, by this reasoning: A higher average speed means less stops per mile and/or less time per stop (thus often implying lighter passenger loading). This means that brakes and door mechanisms, as well as wear on the engines caused by accelerations and dynamic braking and by heavier passenger loads are all less frequent as the speed increases. Since these comprise the major repair calls on and off the road handled by the local shops, the incidence per mileage or the severity (i.e. cost per repair) per mile should be less.

Such assumptions are partially supported by table

In table 3 the IRT division, which has four inspection and light maintenance shops, is taken route by route to compute the average stops per mile for each shop. In other words, on the 242nd Street to South Ferry route, which schedules 13,407,000 car miles per year, there are 38 stops in the 14.73 one-way route miles, or 2.58 stops per mile. Note that the annual scheduled mileage must be supplemented by "idle" mileage (trains being transferred between yards and from yards to stations for repair work or service requirements) and "extra" mileage (for summer and cold weather extra service schedules, baseball or Christmas shopping specials, etc.) in order to compute the total cost per car mile.

The budgeted inspection and repair costs were computed using the real wage formulas and including all material costs except those attributable to shop upkeep and time-based projects such as painting. Labor and material costs for such procedures as car cleaning, which takes place periodically when the car is in storage, without regard to its mileage, are omitted. On systems where car cleaning was performed on a mileage basis, this cost would have to be included.

Also omitted are non-shop expenses such as administration, record-keeping, and road car inspection. The last refers to emergency inspection and repairs of cars in revenue service which are delaying or endangering the operation. A strategically placed force of mechanics is deployed

Table 3

Frequency and Cost of Repairs by Shop, New York

<u>Shop</u>	<u>Avg. Stops per Mile</u>	<u>Scheduled Annual Revenue Mileage (000) 7/1/66- 6/30/67</u>	<u>No. Cars Inspected and Repaired 3/1/66- 2/28/67</u>	<u>Budgeted Inspection & Repair Cost (\$000) 7/1/66- 6/30/67</u>	<u>Cost per Car Handled (\$)</u>	<u>Cost per Car Mile (A) (\$)</u>	<u>Average Miles per Inspection Two Weeks 2/15 - 2/28/67</u>
240th St.	2.25	28,921	4,900	1,070	\$ 214	3.56¢	8200
Pelham	2.38	22,662	3,672	782	213	3.31	7900
239th St. (B)	1.65	60,795	10,438	2,074	198.50	3.28	9750
Corona	2.00	15,244	2,200	493	224	3.25	7950
Concourse & Pitkin	N.A.	N.A.	21,339	2,004	94.20	2.95	New 9350 Old 1900
Jamaica	N.A.	N.A.	21,776	1,423	65.40 (C)	3.36	2150 (C)
Coney Isl.	N.A.	N.A.	7,536	1,219	162	2.41	8300
E. New York	N.A.	N.A.	3,952	941	238	5.20(D)	New 7900 Old 2850 (D)

(A) Includes non-revenue mileage (transfer for repairs and storage) and non-scheduled service mileage (beach and snowstorm service).

(B) Includes 180th Street and Jerome inspection shops.

(C) Older equipment getting four times as many inspections as newer equipment in other shops, with no apparent effect on expenses.

(D) Here, however, older equipment (forms bulk of fleet at this shop) does affect costs.

at signal towers throughout the system for this purpose, with another group patrolling the city in automobiles. These men are positioned according to the passenger and train congestion, and frequency of breakdowns affecting service. They are fully utilized only during the rush hours. The amount of slack at other times, and the lower density of trains and passengers, would make any consideration of the variation of road car inspectors with mileage academic.

The apparent differences in cost per car mile in table ~~three~~ may be due as much as the size of the shop (measured in number of cars handled per year) and the age and peculiarities²¹ of the equipment as to speed. For example, the oldest equipment on the IRT in revenue service, outside of the handful of Third Avenue el cars housed at 239th Street yard, are the R-12, 14, and 15 cars in use on the Broadway line and assigned to 240th Street yard. Put in service in 1946 and 1947, these 350 cars comprise more than half the cars at 240th shop - which has the highest cost per car mile for routine maintenance, even though it does not have the highest number of stops per mile.

Repairs may also be a function of exposure to vibration and contamination with steel dust as mileage is accumulated, or related to passenger loading. In any event, the data do not allow statistical determination of the way in which inspection and light maintenance costs vary according to the speed on the route, although better

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information might. The previously computed costs per car mile of equipment maintenance are not the full costs: to these must be added the additional costs of major repairs referred from the local shops to the base shops. The base shops perform all major overhaul work which is time based in some cases (painting or seat replacement, for instance) and mileage based (although not always scheduled by mileage) in others. They also perform repairs referred from inspections and road failures.

The work force at the base shops is flexible, being used for overhaul and project work when road failures and inspection referrals are light, and concentrated on repairs when necessary, always giving first priority to providing sufficient cars for scheduled service. In 1966, due to various causes, maximum effort was being focused on repairs with some overhauls being slowed down.

While it is safe to assume, after deducting labor and material applicable to supervision, shop upkeep, painting, etc., that the remaining costs are due at least in part to time-based projects, there is no way of ascertaining what part are. Who is to say, for instance, whether replacing the air-brake piping in 40 cars is the result of millions of miles or 30 years of service; or what proportion of a car maintainer's time is spent doing this. Thus any split will be arbitrary. The data for the two base shops are: 207th Street: Labor (computed as previously described from quota sheets) \$10,913,000; Materials 4,329,000; Mileage 230,000,000; Coney Island: Labor 4,449,000;

\$4,449,000; Materials 1,234,000; Mileage 86,000,000.

Costs per car mile are 6.63¢ and 6.61¢ respectively. Arbitrarily defining the mileage-variable part of this cost as 5¢/mile, and adding to it the previously computed (Table 3) inspection and light maintenance costs gives a combined cost per shop varying from 7.41¢ to 10.20¢ per car mile.

Bus Maintenance Costs

These costs are no more suggestive of the effect of average speed on maintenance cost than are the data on rapid transit costs. Transit Record lists the costs by borough, as shown in Table 4 for the fiscal year 1965-66.

TABLE 4

Bus Maintenance Costs per Mile Relative to Speed of Operation

<u>Borough</u>	<u>Avg. Miles per Hour</u>	<u>Avg. Mainten. Cost per Mile</u>	<u>Scheduled Total Mileage, 1966-67</u>
Manhattan	5.86	23.64¢	4,321,000
Brooklyn	7.18	27.45	39,872,000
Queens	8.42	21.83	14,673,000
Staten Island	10.44	21.64	8,603,000

The costs in Table 4 include base shop and administrative costs allocated by mileage. If the budgeted garage expenses only (excluding base shop and administrative

expenses) are divided by the mileage, the descending order according to average speed reads smoothly at 21.4, 16.7, 16.8, and 15.4 cents per mile--although there is still little difference between the latter three. (Average speed in miles per hour includes terminal time, being the total revenue miles divided by the total revenue hours; running speed is thus somewhat higher.)

The exact lower cost per mile of maintenance using the same procedure developed earlier for rapid transit maintenance costs shows even less conclusive results (see Table 5). The procedure as before was to first compute the labor cost, including allowances and benefits, of employees engaged in inspection and repair based on or related to mileage; then add materials costs. Exhibit 6 in the Appendix lists the calculations for the Manhattan bus garage.

In addition to labor costs and material costs (which exclude tire rental at 1¢ per mile, and diesel fuel oil, discussed under Power and Fuel), Table 5 shows the average speed for each depot. This was calculated by first determining the average speed per line, using maximum running time (usually scheduled for 12 to 16 hours of the day) and route mileage data; then multiplying each line's speed by its mileage; then dividing the totals for each depot.

These are the costs that will actually vary with

Table 5

Variable Mileage Cost Per Depot

<u>Depot</u>	<u>Average Scheduled Running Speed</u>	<u>No. Of Bus Lines</u>	<u>1966-67 Scheduled Mileage (000)</u>	<u>Labor Cost (\$000)</u>	<u>Material Cost (\$000)</u>	<u>Total Cost (\$000)</u>	<u>Cost in Cents per Mile</u>
<u>Manhattan</u>	7.20 mph	5	4.320.7	495.7	69.3	565	13.05
<u>Brooklyn</u> Fifth Ave.	8.48	14	6991.3	625.3	128.4	753.7	10.80
East N Y	8.62	12	7378.3	615.3	82.5	697.8	9.46
Crosstown	8.74	7	3701.9	336.4	50.4	386.8	10.45
Fresh Pond	8.76	10	6579.9	585.8	115.4	701.2	10.65
Flatbush	9.46	11	8136.4	645.8	106.5	752.3	9.37
Ulmer Park	10.10	12	7084.5	576.5	120.7	697.2	9.84
<u>Queens</u> Jamaica	10.35	15	7400.8	655.3	92.6	747.9	10.10
Flushing	11.45	18	7271.8	625.3	125.2	750.5	11.35
<u>Staten Island</u>	14.45	19	8603.4	652.8	182.4	835.2	9.70

changes in mileage due to changes in routes or schedules. As Tables 4 and 5 show, there is only a slight correlation with speed. The reason for the persisting lack of clear difference according to speed outside of Manhattan lies in two areas. First, the age of the equipment assigned to each depot tends to distort the extremes of the data: The bulk of the Staten Island fleet operating at the highest speeds is comprised of the next most ancient equipment in the system (1956), while 90% of the mileage in Manhattan at slow speeds is accomplished by relatively new equipment (1963).²²

The effect that equipment age can have is shown in Table 6, which lists costs fully allocated as computed by the Authority for maintaining each type of bus for two months (July and November) of 1966. Note that emphasis apparently shifted from attending to older equipment to attending to newer equipment in this period. . . .

TABLE 6

Maintenance Costs by Type of Bus

<u>Type Bus</u>	<u>No. Owned Nov.1966</u>	<u>Year in Service</u>	<u>Assign*</u>
GMC5101	172	1948	2/3B 1/3Q
MackC-49	318	1956	1/4B 3/4SI
GMC5106	209	1957	$\frac{1}{2}$ B $\frac{1}{2}$ Q
GMC5106	121	1958	all B
GMC5301	190	1959	2/3B 1/3Q
GMC5301	305	1960	B(a few M)
GMC5301	130	1961	all B
GMC5301	175	1962	all Q
GMC5303	350	1963	$\frac{1}{2}$ B1/3M, rem. in Q&SI
Flexible	165	1964	all B
Flexible	190	1965	$\frac{1}{2}$ B $\frac{1}{2}$ Q

<u>Type Bus</u>	<u>Nov.1966 Miles/Bus/Mo.</u>	<u>Maintenance July 1966</u>	<u>Cost/Mi. (¢) Nov.1966</u>
GMC5101	765	87.02¢	14.88¢
MackC-49	2690	18.89	16.38
GMC5106	1460	19.01	15.78
GMC5106	2220	13.88	13.64
GMC5301	2400	15.73	16.76
GMC5301	2090	19.40	17.63
GMC5301	2560	9.68	13.89
GMC5301	2790	9.68	13.79
GMC5303	2810	8.61	9.36
Flexible	3030	5.87	7.45
Flexible	3150	3.73	5.74

*The Assign column refers to the assignment of the buses to the various boroughs, shown as fractions of the mileage run by each type in two or more boroughs. Brooklyn = B, Queens = Q, Manhattan = M, Staten Island = SI.

Since the newer equipment is used more intensively, the chances are that any additions to mileage, particularly in peak hours, will be operated by older equipment at a somewhat higher cost; although how this would affect the computed costs on the previous page is difficult to say, since most depots contain a mixture of vehicle ages.

The costs per mile listed above are for the most part higher than those on the previous page because they include the Base shop costs. This shop, located in East New York, does all major repair work for all four boroughs, and incurs computed real variable costs of \$4,310,800 per year (1967), or 6.4¢/bus mile. Thus for Manhattan, the total variable cost of maintenance per bus mile would be $13.05 + 6.4 = 19.45\text{¢}$.

Unfortunately, the Base shop does not do an equal proportion of major repair work for all boroughs. Staten Island in particular, being somewhat removed from the Base shop, and only recently becoming accessible by other than ferry, shows a proportionately larger budget for engine, transmission, etc. parts than would be expected from looking at budgets for other depots.

This is the second reason for the muting of the reduction of maintenance costs with increase in speed in the data. The flexibility necessary for efficient operation both

in assigning maintenance tasks and in assigning types of busses to the various depots makes determination of the cost of an added or subtracted mile on the basis of the data presented here at best only an approximation, at worst an educated guess. As in the case of rapid transit car maintenance, the overlaps which cloud the distinctions necessary could only be cut through by a detailed analysis of the maintenance experience by speed for each vehicle type. This would certainly be feasible, but would require some additional accounting classifications.

For purposes of the model, then, the computed costs per mile by depot, plus the computed base shop cost per mile would be considered the variable maintenance expenses.

Power and Fuel

Power is presently supplied to the NYCTA under several different contracts by Con Edison. Most of the power used to run the trains is delivered either to a NYCTA power plant, which funnels it to various substations, or to the substations directly. For these services, Con Ed bills the Authority monthly, at a "composite" rate of 1.37¢/kw-hr. for substation delivery, and 1.29¢/kw-hr. for plant delivery (rates for the Rockaway line, split between Con Edison and Long Island Lighting, are somewhat higher). The total cost

of this delivered power is budgeted at \$26,670,000 for the current fiscal year, about two-thirds of the power department budget (most of the rest is consumed in maintaining and operating the substations and cables).

The "composite" rate is made up of three components, which Con Ed lists separately in their contracts and on their bills. These are the "demand" portion, the "energy" portion and the "fuel correction" portion of the "composite" rate. The "demand" charge is based on the peak usage of power in the peak half hour each month, and comes to one-third to one-fourth of the total cost, depending on the contract. Since the system is operating at practical capacity during the peak half hour, no marginal change in schedules or routes will affect this part of the rate, unless it involves a reduction in service at that time, hardly a likely possibility in New York.

Table 7 gives the demand and energy rates for plant and substation delivery:²³ . . .

TABLE 7

Electric Power Rates, New York SubwaysPlant Delivery Contract (IRT & BMT Div.)

<u>Charge</u>	<u>Rate</u>	<u>Monthly Peak & Annual Consumption Bases</u>
Demand	\$1.1875 per kw.	296,000 kw/½hr. in July to 325,000 kw/½hr. in Jan.
Energy	0.855¢ per kw-hr.	1,275,886,000 kw-hrs./ yr.
Fuel Correction	0.097¢ per kw-hr.	

The range in peak consumption is due to the use of heaters in the winter and the somewhat reduced passenger volume in the summer months.²⁴

Substation Delivery Contract (IND Div. & Rockaway Line to Broad Channel)

Demand	\$26,205 for the 1st 20,000 kw. \$1.25 per add'l. kw.	174,000 to 197,000 kw/½hr.
Energy	\$2,834.60 for the 1st 250,000 kw-hrs. 0.90¢ per add'l. kw-hr.	705,141,000 kw-hrs./ yr.

The volume of power consumption is of such magnitude that no attention need be paid to the graduated rates for the first 20,000 kw. or 250,000 kw-hrs. in computing the cost of marginal changes in power consumption.

The cost (energy portion) of an added or removed car mile can be computed on an average basis by simply dividing the annual kw-hrs. by the annual car miles. In both contracts this comes to 6.3 kw-hrs. per car mile, or 5.4¢ and 5.7¢ per car mile respectively. However, this says nothing about how the cost varies with speed and loading. The average cost will vary with the weight of the car and of its passenger load, the distance between stations, the type of rolling stock and the weather (heaters and fans). The information necessary to make these computations for New York's rapid transit lines is given in Exhibits 7 and 8, Appendix.

For example, let us assume the following timings as representative and, using the data in Exhibits 7 and 8, compute the power consumption: . . .

TABLE 8

Power Consumption, Grand Central
to Brooklyn Bridge Stations, IRT

<u>Local:</u>	<u>Time²⁵ (incl. stop)</u>	<u>Kw-Hrs. Accel.</u>	<u>Kw-Hrs. Motion</u>	
GC to 33	1½ min.	3.384	.5	
33 to 28	1	2.696		Assume seated
28 to 23	1	2.696		load, 15 seconds
23 to 14	1½	3.384	.5	coast & brake,
14 to Ast	1½	3.384		15 seconds sta-
Ast to Bleek	1½	3.384		tion stop, no
Blk to Sprng	1	2,696		grades
Spg to Canal	1	2.696		
Can to BkBdg	1½	3.384	.5	
	<u>11</u>	<u>27.704</u>	<u>1.5</u>	

Lights, etc. $11/60 \times 2.0 \text{ kw/hr.} = .367 \text{ kw-hrs.}$

Total 29,571 kw-hrs. $\times .855\text{¢} = 25.28\text{¢}/3.14 \text{ miles} = \underline{8.05\text{¢/mi.}}$

Express:

GC to 14	3½	3.384	4.166
14 to BkBdg	<u>4</u>	<u>3.384</u>	<u>5.166</u>
	7½	6.768	9.332

Lights, etc. $7\frac{1}{2}/60 \times 2.0 \text{ kw/hr.} = .250 \text{ kw-hrs.}$

Total 16.350 kw-hrs. $\times .855\text{¢} = 13.98\text{¢}/3.14 \text{ miles} = \underline{4.55\text{¢/mi.}}$

Thus the cost per car mile of running local, making all stops in this route segment, is nearly twice that of running express.

The fluctuation in the cost of fuel per bus mile is largely related, as most automobile drivers well know, to the amount of traffic congestion and number of stops (reflected in average speed) and to the age and type of vehicle. For the year ended 6/30/66, the following results

were obtained:

TABLE 9

Fuel Cost by Borough

<u>Borough</u>	<u>Mi./Gal.</u>	<u>Mi./Hr.</u>	<u>Fuel Cost per Mi. (¢)</u>
Manhattan	3.67	5.86	3.01
Brooklyn	3.77	7.18	2.78
Queens	4.12	8.42	2.57
Staten Island	4.92	10.44	2.12

It should be noted that precise calculation of the fuel costs on a given route cannot be accomplished in the same way as was done for rapid transit, because the variability in number and length of stops, traffic congestion and driver control introduce far more variation in bus operation than exists in rapid transit operation.

Records by borough are kept on the fuel cost by type of bus. The same trend of cost inversely related to speed reveals itself where a given type and age bus operates in two or more boroughs. Table 10 gives the data for fiscal 1965-66. . . .

TABLE 10

Fuel Cost by Type of Vehicle

<u>Type Bus</u>	<u>Year</u>	<u>Fuel Cost Per Mi. (¢)</u>	<u>In Manhattan</u>	<u>In Brooklyn</u>	<u>In Queens</u>	<u>In Staten Island</u>
GMC 5101	1948	3.14		2.99	3.44	
MackC-49	1956	2.17		2.64		2.02
GMC 5106	1957	2.56		2.74	2.35	
GMC 5106	1958	2.56		2.56		
GMC 5301	1959	2.50		2.53	2.44	
GMC 5301	1960	2.71	2.92	2.70	2.27	
GMC 5301	1961	2.61		2.61	2.76	
GMC 5301	1962	2.29			2.29	
GMC 5303	1963	2.49	2.71	2.46	2.33	1.96
Flexible	1964	2.67		2.67		
Flexible	1965	2.58		2.68	2.43	

(See also Table 6 for additional data on assignments and maintenance costs by bus type.)

Notice that the GMC TDH-5303 model buses delivered in 1963, used in all four boroughs, show a steadily decreasing fuel cost with increasing speed, due to increasing miles per gallon. (The price per gallon of fuel is the same in all boroughs.)

The cost of oil was included in the maintenance tables.

Maintenance of Way

We enter here into the categories of costs less clearly related to such quantities as car miles. While many of these would seem in theory to be a function of the quantity of service rendered, in actual practice they appear to vary little, if at all, with additions or subtractions in service. In the case of maintenance of way, several approaches are possible to ascertaining the marginal costs of service or route changes.

Maintenance of structures such as garages, shops, stations, tunnels, buildings, etc. as well as administrative costs and cleaning functions are obviously independent of either service or passenger traffic. A. Scheffer Lang and Richard M. Soberman²⁶ suggest a correlation between ton miles per mile of track per year and the cost of maintaining the mile of track. However, their data compares gross budgets from different cities, introducing the possibilities of different standards, physical conditions, etc. and does not probe the basis for the expenses listed. It appears as though New York, at least, shows little sensitivity in its expenditures for the maintenance of track, ties, ballast, signals and electrical structures to changes in car or ton mileage. There are several reasons for this.

For one, the ratio of track wear to mileage operated is small. Normal track life varies generally from 7 to 20 years with a range of 1.4 to 29.3 million ton miles per hour.²⁷ The ratio of track wear to increase in ton mileage is thus about 3:20. Where track is replaced more often, it is not because of ton mileage, but for other reasons. Track on curves, for instance, requires replacement often every 12 to 18 months.

Ties vary in life from 15 to 20 years. Ballast is replaced more often, but largely because of factors which foul the ballast, such as floods, steel dust, weather.

Furthermore, the replacement schedules for the roadway elements are not based on mileage of any sort. They are based on inspection-revealed need.²⁷ Records are not even kept of the dates of replacement of rails, etc.

In the case of rail replacement, for example, three methods of inspection are used. Every three months a Sperry rail detector travels every track in the system checking for hidden flaws and defects. Broken rails are replaced immediately, flawed or misaligned rails scheduled for appropriate action. Twice a year, a team of expert track bureau officials rides a train over the system to test the ride. Finally, trackwalkers report various conditions and defects found along the right of way.

Another reason for the lack of sensitivity of costs to changes in car-miles is that a large proportion of the track and signal labor force is stable. This is because much routine inspection work involves the dismantling and putting together of apparatus which, were it to be repaired, would merely require the replacement of a part in the already dismantled apparatus (this is especially true for signals).²⁷ Another reductive factor in signal maintenance is that the relays are activated with the passage of each train, not each car, so that lengthening or shortening of trains on the same headway will not alter signal repair.

Then too, we are talking of changes which represent only a small bite in an already impressive set of data. One line like the Flushing IRT line operates about fifteen million car miles per year, of which 7,000,000, or nearly half, take place in the peak 20 hours a week. Put another way, of 118,200 tons per peak mile of track each weekday, 63,000 occur in the five peak hours. The most lavish increase in service on the line, providing seats for all passengers except when maximum service (every 120 seconds or less) is provided, without increasing headways to any station, and extending express service all day until midnight, would increase car mileage by only 8% per year.

More significantly, the change in labor and materials

quotas in the budgets for the World's Fair operation on this same line, which required 40% more mileage per year (6,000,000 miles) were entirely for train crews, bus drivers and dispatchers, and three road car inspectors later shifted to another point on the system. No changes were budgeted in any other department (except for station department employees, which was a traffic-related cost) including maintenance of way, equipment, power, injuries and damages. There is apparently a considerable flexibility in the existing system.

This flexibility may be due to the size of the operation, of course, and may thus be unique to New York.²⁸ In the light of the existing data, however, it must be assumed that the effect of any marginal service change on maintenance of way costs is negligible. This would not refer to changes in schedules involving capital investments such as changes in speed; but we are not dealing with capital investments here.

There are no maintenance of way costs in bus operations to the operator. Tax relief is universal among publicly owned bus systems, with only rare exceptions, so that any street repairs are paid by the city or its occupants. However, it is doubtful that the operation of buses on a street materially affects the cost of repairing and maintaining it,

with the possible exception of a lightly traveled, non-truck street with heavy bus traffic, such as might be found around a bus garage. For all practical purposes, however, there is no variable cost for surface transportation in this category.

Injuries and Damages

This category falls into a group of costs properly related to the number of passengers carried, rather than the mileage operated, with the exception of bus traffic accidents. Other quasi-variable costs in this group include those of the station department and police. The provision budgeted each year for claims and accident costs is based on the past year's experience, but the amount that is actually spent is a function of the passenger traffic.

The budget for the Law Department plus the reserve for Public Liability can be considered the applicable costs. These were budgeted at 7,920,000 dollars for the current fiscal year. The equivalent accounted listing for the previous year is \$8,926,000, including non-variable administrative and related expenses of other departments. Here again the accounted breakdown shows decreasing costs with increasing speed in the various boroughs when the unit of measurement is the bus mile. Since vehicle injuries rather than passenger injuries may dominate the costs in surface

operations, it might be appropriate to measure the latter using vehicle miles, while measuring the costs in rapid transit operations as a function of passengers.

The data for surface operations list:

<u>Borough</u>	<u>Cost per Mile</u>
Manhattan	9.28¢
Brooklyn	6.22¢
Queens	3.17¢
Staten Island	1.96¢

The remaining five million dollars allocated to the rapid transit operations imputes a cost of 0.38¢ per passenger carried. Many passenger accidents take place in the rush hour, because of the extreme congestion and density of movement at those hours; thus the cost per passenger added or subtracted at other times, when most schedule and route changes would take place, is probably much lower. Unfortunately, the necessary secrecy shrouding this area of cost (claims may take as long as ten years to be settled) prevents a more revealing analysis of the data. The following observations, however, can be made:

- 60% of the rapid transit accidents do not occur on board the cars.

- Where extra mileage or faster scheduled speed means less congestion, the accident rate would probably be lower.

- Faster acceleration and deceleration rates on newer

equipment are causing passenger injuries.

-A low-income passenger is less likely to have the time, money or inclination to claim damages.

Depreciation and Other Time-Related Costs

In theory, it would seem as though significant changes in mileage would affect this category of costs, not through additional capital investment, but through faster write-offs or more frequent repairs. In practice, however, the criteria applied here are similar to those discussed under maintenance of way costs. The life of a bus or subway car is independent of its annual mileage consumption, the latter being adjusted to through changes in the cost of equipment (or structure) maintenance.

One measure of this independence is the fluctuation in annual mileage per vehicle amongst major transit systems, and more importantly, within the New York system: . . .

TABLE 11

Annual Mileage by City and Line

<u>City</u>	<u>Annual Mi./Bus</u>	<u>Annual Mi./Car</u> ²⁹
London	44,917	76,432
Paris	25,000	38,000
Chicago	35,200	38,200
Boston	24,100	
New York	29,000	44,500
NY: 241-WP line		59,300
Woodlawn		53,400
Pelham		50,500
242-Broadway		44,000
145-Lenox		43,600
Jamaica BMT		42,300
Flushing		38,000
East-Dyre		34,900
Myrtle Ave.		28,000

The cars on all the above New York lines are considered to have the same life (except the last, which is using older, rehabilitated cars).

The life of a rapid transit car in New York is now considered to be 35 years. This is based on a recommendation made by a consultant in an internal (unpublished) report dated 1961. It is unlikely, however, that the recommendation was based on mileage considerations, as it did not specify any variation in life according to mileage.

Prior to 1961, the life of a car was considered to be

50 years. One of the primary reasons for the lower life revision was a reduction in maintenance procedures during the 1950's; another was the fact that the city pays for new cars, while the Authority pays for maintaining them.

A look at Table 3, page 234, will show how expenditures increase for older equipment. Inspections of older cars, for example, must be done three or four times as often as those for newer cars. There is thus a tradeoff between increasing maintenance costs with age and the cost of buying a new vehicle. Just how this tradeoff is related to mileage cannot be deduced from the available data.

Furthermore, as was demonstrated earlier, the most lavish increase in mileage would, in most cases, be only a small increase over existing operations. Within the range of values exhibited in the above table, any such variation is more than adequately covered.

The costs such as depreciation and maintenance of way which are time-related when referred to schedule and route changes within an existing system are, of course, relevant considerations in discussing capital investment or system expansion. In this case, the first costs are sunk investments.³⁰ It costs a certain amount of money to buy a vehicle good for X years, or to maintain a section of track for operation at Y speed. Once this basic investment is

being provided, however, the fluctuation in mileage or usage will have little effect on such costs.

Thus from any point of view, the operating company's or the community's, the costs of additions to or subtractions from service within an existing system--the restructuring of a given arrangement of fixed capital--will lie largely in operation, power or fuel, and equipment maintenance. To the extent that there is a change in passenger revenue, certain other costs such as injuries and damages will also change.

Cost of No Service

One alternative change in a schedule or route is to eliminate it, for part or all of the day. If this takes the form of closing a station at night, or eliminating non-rush hour service on a bus line, or shortlining (turning some vehicles short of the farthest terminal), the changes in cost will be reflected in the variable costs analyzed earlier. However, if peak vehicle requirements are reduced, or capacity requirements reduced, or an entire line shut down, then other costs come into play. This is not likely to be the case in most schedule and route changes, but might occur for instance in rearranging bus routes to coincide with the opening of a new rapid transit line.

The vehicles thus eliminated will at some point either

represent non-capital investment availability of equipment for additions elsewhere, or reduce the need for as many new buses over a given period. They might be sold, used. Unless a significant portion of the fleet is involved, the oldest will be disposed of first. This means that there is a savings equal to the cost of that many new vehicles. If the company uses bonds to purchase equipment, the savings will be amortized over the usual life of the bond. If, as in New York, new equipment is generally paid for out of city funds, the money will probably be diverted elsewhere, perhaps to some rehabilitation project on an older rapid transit line.

Where a rapid line is eliminated entirely, maintenance of way and structure (stations, track, etc.) becomes entirely variable and must be determined for that segment.

Summary

The cost functions developed for incremental changes in service in New York are recapitulated in Table 12. . . .

TABLE 12

Summary, Variable Costs, New York

<u>Category</u>	<u>Rapid Transit Cost</u>	<u>Bus Cost</u>
Operating Labor	$w_i = (1+P)r_i \quad 1.09 + 519$ <p>where r_i = base wage rate P^1 = % base wage for allowance w_i = real wage</p> <p>\$10,019 per year for motormen, fiscal 1967</p>	
Equipment Maintenance	7.41 to 10.20¢ per car mile, depend- ing on speed, age of vehicle, size of shop. Statistical functions relating cost to these factors could not be determined with available data.	15.77 to 19.45¢ per bus mile, depending on same factors.
Power or Fuel	Local 8.05¢/mi. Exp. 4.55¢/mi. See Tables 7 and 8	1.96 to 3.44¢ per bus mile, depending on speed and age (page 257).
Maintenance of Way	None	None
Injuries and Damages	0.38¢/passenger	1.96 to 9.28¢ per bus mile, depending on speed.
Depreciation ³⁰ (for peak hour incre- ments only)	\$40.60/non-hol. weekday per vehicle	\$14.30/non-hol. weekday per vehicle

Thus for increments of service not requiring additional equipment, the marginal cost is the cost of the operator, if any, plus 11.96 to 18.25¢/mile and 0.38¢/passenger in rapid transit service, or 19.69 to 32.17¢/mile for bus service. The low numbers would be for new equipment operating at high speeds and serviced at one of the larger depots.

Comparing the mileage costs for the included accounts (categories) to the "fully allocated" costs for the same accounts in Transit Record, for fiscal 1967, we get:

<u>Account Category</u>	<u>Rapid Transit</u>		<u>Bus</u>	
	<u>Computed</u>	<u>Allocated</u>	<u>Computed</u>	<u>Allocated</u>
Equipment Maintenance	7.41-10.2	14.11	15.8-19.5	21.22-24.86
Power or Fuel	4.55-8.05	11.06	1.96-3.44	2.28-3.25
Injuries or Damages	(per Pass.)	(per Mi.)	1.96-9.28	2.07-9.07
Total	11.96-18.25	25.17	19.69-32.17	25.57-37.18

(All costs are expressed in cents per mile.)

Rapid Transit costs in these categories are thus computed at about 60% of the allocated costs, while bus costs range from 77% to 86% of the allocated costs. Note that in the bus costs, fuel and accident costs are pretty much the same; the difference is in the equipment maintenance account.

It is probable that these percentages could be applied to other systems, or to growing costs on New York's system, to obtain the appropriate factual cost data for increments of service.

Boston

The Massachusetts Bay Transportation Authority does not publish anything like New York's Transit Record. Their annual reports do not list the annual vehicle miles operated. The difficulty of obtaining detailed cost information in Boston³¹ required reliance on the MBTA's official variable cost figures,³² which are less than the fully allocated cost for the account categories, but which do include such charges as maintenance of way.

The hourly wage rate for bus, streetcar and rapid transit operating personnel is currently about \$3.75 an hour. When all allowances, etc. (except overtime) are included, this comes to about \$5.25 an hour. This is about the same real wage as is paid in New York. (Note that the cost per mile, however, need not be the same if the scheduled speed is slower or faster.)

The variable mileage costs for bus and rapid transit operation in Boston are given as 43¢ and 69¢ respectively. The fact that these are double or greater the costs in New

York does not mean that fixed costs are necessarily included.
(See Footnote 31). These figures were used throughout
Chapter VII in computing costs of alternatives in the
examples on the Boston system.

Footnotes

1. Adhering to the standard system of account classification established by the accounting profession.
2. The costs of new equipment have been partly paid in recent years by a bond issue and federal monies, thus bringing the city's contribution down somewhat.
3. Annual Report, Chicago Transit Authority, 1966, p. 24.
4. Annual Report, 1965, p. 50-51 (assuming one 1968 Br. pound = \$2.40).
5. 6,153 employees for maintenance of way (rapid transit). The total personnel quota for fiscal 1967 was 33,861.
6. Recently renamed divisions A and B with the opening of a new link between the BMT and IND in November, 1967.
7. New York City Board of Transportation, Report for the three and one-half years ending June 30, 1949, p. 91.
8. The Flushing line is a hybrid line: it is considered part of the IRT, is IRT gauge, but sends cars for major repairs and overhauls to Coney Island via a physical connection to the BMT because there is no connection to the IRT mainlines.
9. Contract R-38.
10. The New York City Transit Authority, it will be recalled, does not operate buses in the Bronx except through its subsidiary. See page 214.
11. See Chapter II, pages 86-87.
12. Or should not be: that is what this chapter is all about.
13. In the absence of any information to the contrary; unlike Social Security, there is no upper limit to the salary base from which this is calculated.

- 14. These times, added to the minimum required lunch, sign off and report times, most closely approach eight hours worked for eight-hour pay. For a further discussion of work program efficiency, see Chapter VII, page 325ff.
- 15. See Chapter V, page 167ff.
- 16. Chapter II, pages 52-53.
- 17. See Chapter IV, page 133 for an alternative formulation.
- 18. Based on interviews with car maintenance personnel during 1966.
- 19. Based on examination by the author of daily car mileage and car status reports.
- 20. The data on inspections and mileage were obtained through special permission of the Car Maintenance Department.
- 21. For example:

Avg. Stops per mile	Shop	No. Brake Failures, 3/66-2/67	Car Miles/ Failure
2.38	Pelham	86	278,000
2.25	240th	158	193,000
1.65	239th	339	188,000

The higher number of brake failures at 239th Street in spite of the lower average stops per mile was due to a problem at the time of compatibility between two brake systems. The cars experiencing this problem were assigned to 239th Street.
- 22. Based on New York City Transit Authority equipment assignment listings.
- 23. Data supplied to the author by the Power Department.
- 24. See Chapter V, Table 9.
- 25. Courtesy Department of Schedules and Traffic Studies; modified slightly (1/2 minute reduction) by author's observations.
- 26. Urban Rail Transit (Cambridge, Mass., 1964), p. 71.
- 27. Data supplied by Maintenance of Way Department.

28. Boston's Harvard to Ashmont line, for example, requires less than one-fourth the rolling stock and runs even less car mileage and ton mileage.
29. Data from Department of Schedules and Traffic Studies.
30. J. R. Meyer, J. F. Kain, M. Wohl, The Urban Transportation Problem (Cambridge, Mass., 1965), list Capital Recovery Factors on page 178. Based on \$30,000 per bus and \$140,000 per car (air conditioned), this comes to \$14.30 per non-holiday weekday for an added bus (\$3580/year) and \$40.60 per non-holiday weekday for an added rapid transit car (\$10,200/year).
The reader will note that the cost functions developed in this reference are not used in this thesis because they are concerned with the "cost of providing comparable urban transport services by different kinds of technologies" (p. 171), focusing on rush hour average costs; while this thesis seeks to analyze the marginal costs at different hours of the day of non-comparable services by the same technology.

31. Due in part to Boston's embarrassing distinction of having the highest costs in the country. Compare this table of total system costs excluding depreciation or fixed charges (all data are from fiscal years ending between December, 1966 and September, 1967):

<u>City</u>	<u>Fully allocated costs per vehicle mile</u>	
	<u>Rapid Transit</u>	<u>Bus</u>
Boston		\$1.78
New York	\$0.911	\$1.332
Chicago		0.814
Cleveland		0.705

Note that New York operates a much higher percentage of bus mileage on heavily congested streets than does Boston, or almost any other city for that matter, which accounts for the high figure for its bus operations. The figures for its Queens and Staten Island divisions, which more closely approximate conditions in Boston, Chicago and Cleveland, were \$1.21 and \$0.98 per bus mile respectively.

32. Communicated to the author by Mr. J. Kelly, Assistant Treasurer, Massachusetts Bay Transportation Authority.

APPENDIX

EXHIBIT 1

2

TRANSIT RECORD

August, 1967

RESULTS OF OPERATION FOR JUNE, 1967 AND TWELVE MONTHS ENDED JUNE 30, 1967

RAPID TRANSIT

Month of June, 1967			Twelve Months Ended June 30, 1967		
Per Cent of Operating Revenue	Cents Per Revenue Car Mile	Amount	Per Cent of Operating Revenue	Cents Per Revenue Car Mile	Amount
97.22	89.99	\$23,538,287	97.63	83.32	\$26,524,295
2.14	1.98	518,040	2.10	1.79	5,665,299
.20	.19	48,719	.22	.19	584,928
.00+	.00+	831	.01	.01	19,476
1.96	1.81	475,214	.00+	.00+	1,485
.44	.40	105,654	.04	.04	128,619
100.00	92.56	\$24,211,641	100.00	85.35	\$26,924,202
18.77	17.38	\$4,545,244	19.21	16.39	\$51,842,589
17.18	15.90	4,160,308	16.53	14.11	44,627,855
11.19	10.36	2,708,592	12.95	11.06	34,966,159
36.27	33.57	8,781,107	48.81	41.66	131,749,824
1.96	1.81	475,214	2.10	1.79	5,665,299
17.15	15.87	4,152,280	20.39	17.40	50,017,310
.....	.....	.....	(13.26)	(11.32)	(35,798,681)
102.52	94.89	\$24,820,745	106.73	91.09	\$288,096,269
.02	.02	5,311	.03	.03	78,141
102.54	94.91	\$24,827,256	106.76	91.12	\$288,174,410
(2.54)	(2.35)	(\$613,615)	(6.76)	(5.77)	(\$18,250,208)
.10	.09	\$24,828	.08	.07	\$217,211
(2.44)	(2.26)	(\$590,787)	(6.68)	(5.70)	(\$18,032,997)
35.99	33.31	\$8,713,614	3.23	2.75	\$8,713,614
33.55	31.05	\$8,122,827	(3.45)	(2.95)	(\$9,319,383)
MISCELLANEOUS OPERATING STATISTICS			MISCELLANEOUS OPERATING STATISTICS		
		236.70			236.70
		719.85			719.85
		877,694			10,638,801
		26,157,644			316,261,591
		216,644			2,618,819
		129,125,560			1,775,261,610
		4.90			5.52
		1,425,100			17,228,475
		114,633,719			1,298,484,890
		4,583,056			4,425,348
		2,041,264			1,970,882
		1,407,856			1,245,999
					2,260,919

BUS

Month of June, 1967			Twelve Months Ended June 30, 1967		
Per Cent of Operating Revenue	Cents Per Revenue Bus Mile	Amount	Per Cent of Operating Revenue	Cents Per Revenue Bus Mile	Amount
99.33	150.33	\$8,352,870	99.21	138.01	\$91,072,207
.61	.93	51,465	.73	1.02	673,402
.04	.06	3,445	.05	.06	41,154
.00+	.00+	103	.00+	.00+	681
.02	.02	1,196	.01	.02	12,505
100.00	151.34	\$8,409,079	100.00	139.11	\$91,799,953
.71	1.07	\$59,515	.74	1.02	\$676,640
17.81	26.95	1,497,230	18.88	26.27	17,335,538
1.91	2.90	160,969	2.04	2.84	1,871,008
48.93	74.06	4,114,900	54.39	75.66	49,926,790
3.59	5.43	302,007	3.73	5.19	3,427,934
15.38	23.27	1,293,086	16.00	22.25	14,688,756
88.33	133.68	\$7,427,707	95.78	133.23	\$87,923,746
.02	.02	1,375	.02	.03	15,990
88.35	133.70	\$7,429,082	95.80	133.26	\$87,939,646
11.65	17.64	\$979,997	4.20	5.85	\$3,860,307
.11	.16	\$8,810	.09	.11	\$75,352
11.76	17.80	\$988,807	4.29	5.96	\$3,935,659
37.53	56.80	\$3,156,154	3.44	4.79	\$3,156,154
49.29	74.60	\$4,144,961	7.73	10.75	\$7,091,813
MISCELLANEOUS OPERATING STATISTICS			MISCELLANEOUS OPERATING STATISTICS		
		558.99			558.99
		548,522			6,341,756
		5,586,140			65,992,170
		9,696			125,143
		1,389,474			16,630,038
		4,401			3.98
		733,384			8,711,139
		39,289,897			434,209,024
		1,532,103			1,434,464
		862,938			814,505
		532,993			486,380
					722,452

() denotes deficit.
(a) See note (a), page 1.

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EXHIBIT

2

NEW YORK CITY TRANSIT AUTHORITY

Comparative Statement of Operating Expenses by Function
For Fiscal Year Ended June 30, 1966 and 1965

RAPID TRANSIT

	Fiscal Year Ended June 30		Increase or (Decrease)	
	1966	1965		
MAINTENANCE OF WAY AND STRUCTURES:				
Superintendence:				
Salaries	\$6,713,739.15	\$6,677,176.40	\$36,562.75	.6 %
Expenses	65,059.54	50,024.25	15,035.29	30.1
Charges from Other Departments	67,336.87	95,353.86	(28,016.99)	(29.0)
Ballast	52,123.69	45,905.22	6,218.47	13.7
Ties	626,112.13	518,000.96	108,111.17	20.9
Rails:				
Running Rails	801,680.64	694,637.32	(2,946.63)	(.3)
Guard Rails	146,021.24	125,823.31	20,197.93	12.6
Rail Fastenings and Joints	674,940.10	609,580.15	65,359.95	10.9
Special Work	246,313.69	172,029.92	74,283.77	43.2
Roadway and Track Labor:				
Trackmen	7,059,736.63	6,151,225.21	908,511.42	6.7
Other Labor	1,680,403.63	1,691,877.64	(11,474.01)	(.6)
Miscellaneous Roadway and Track Expenses	2,717,101.62	2,222,765.73	494,335.89	20.6
Cleaning and Sanding Track	725,537.00	639,678.69	85,858.31	13.4
Removal of Snow, Ice and Sand	100,591.17	391,565.35	(291,274.18)	(74.3)
Repairs of Tunnels:				
Repairs	384,430.37	145,223.57	239,206.80	164.7
Painting	12,654.94	1,638.16	11,016.78	650.3
Drainage	297,505.33	207,050.81	90,454.52	1.1
Ventilation	541,128.83	515,660.14	25,468.69	5.7
Lighting System	556,932.29	535,021.16	21,911.13	2.2
Repairs of Elevated Structures and Tunnels:				
Repairs	1,000,123.13	1,000,123.13	(.00)	(.0)
Painting	66,150.60	170,773.18	(104,622.58)	(33.7)
Repairs of Bridges, Trestles and Culverts	19,564.87	2,757.11	16,807.76	609.6
Repairs of Crossings, Fences and Signs	27,795.20	26,412.63	1,382.57	(29.2)
Repairs of Signal and Interlocking Systems	5,019,502.27	5,450,637.61	(431,135.34)	(2.9)
Repairs of Fire Protection Equipment	37,424.43	301,133.65	(263,709.22)	(12.6)
Telephone and Telegraph Repairs	481,033.23	455,715.20	25,318.03	5.3
Other Miscellaneous Way Expenses	1,130,675.20	922,732.32	207,942.88	21.0
Distribution System Repairs:				
D. C. Feeders	103,124.14	137,630.20	(34,506.06)	(.6)
Track Bonding	1,000,123.13	1,000,123.13	(.00)	(.0)
Third Rail and Mains	2,000,123.13	2,000,123.13	(.00)	(.0)
Miscellaneous Electric Line Expenses:				
Lighting System	66,020.16	67,204.63	(1,184.47)	(1.6)
Other Expenses	50,772.76	47,034.67	3,738.09	21.2
Repairs of Buildings and Structures:				
Car Houses, Repair Shops and Inspection Shops	405,071.04	401,431.07	3,639.97	(0.6)
Stations, Waiting Room and Platforms	5,220,237.23	5,700,431.69	(480,194.46)	(8.2)
Other Buildings	351,552.04	307,014.44	44,537.60	3.7
Attendance:				
Vacations	3,105,759.65	2,673,697.63	432,062.02	20.2
Holidays	1,320,564.39	1,321,616.70	(1,052.31)	(.1)
Sick Leaves	941,572.84	389,287.00	552,285.84	4.7
60% Sick Leaves	22,620.85	31,487.54	(8,866.69)	(28.2)
Jury Duty	66,124.32	73,634.61	(7,510.29)	(10.1)
Death in Family	38,475.78	30,223.47	8,252.31	7.1
Mar. Allowances	49,120.50	15,797.66	33,322.84	211.1
Differential Pay (Night)	51,522.30	48,122.22	3,400.08	66.5
Total Maint. of Way & Struct.	\$37,029,369.69	\$36,067,659.62	\$961,710.07	2.6 %

EXHIBIT 3

OPERATING BUDGET - FISCAL YEAR ENDING JUNE 30, 1967
DETAILS OF PERSONAL SERVICE

Line No.	Title	Rate \$	No. of Empls.		Pay-Hours (Weekly Payroll)	Budget Allowance \$
			Full Time	Part Time		
STATION DEPARTMENT, BUDGET 31						
	<u>Annual Employees</u>	<u>Actual</u>				
1	Clerk (Grade 5) X	8,250	1			8,250
2	Clerk, Supervising (14)	6,950	2			14,140
	Annual Increments	240				
3	Clerk, Senior (10)	5,990	4			22,711
		5,530 (5,543)	2			
		5,030 (5,078)	1			
	Annual Increments	110				
4	Clerk (7)	4,830 (4,892)	2			9,222
		4,240	1			
	Annual Increments	90				
5	Inspector of Service (Safes)	9,152	3			27,456
6	Stenographer (8)	4,470	2			8,740
		4,180	1			
	Annual Increments	90				
7	Superintendent, Senior (Stations)	15,300	1			15,300
8	Superintendent (Stations)	13,225	1			13,225
9	Supervisor, Station	10,848	20			198,753
		9,925	2			
		9,537	16			
	Special Assignments	8,506	1			
	Annual Increments	214				
10	Supervisor, Assistant Station	8,183	144			1,140,017
		7,926	2			
		7,409	132			
		6,895	9			
	Overtime (500 hrs. at \$3.80/hr.) ...	1,900	1			
	Annual Increments	1,943				
11	Typist (7)	4,650 (4,725)	1			4,810
	Annual Increments	85				
	Total Annual Employees		181	--	--	1,462,624

(a) Coordinator of Cleaning.

EXHIBIT 3 (cont.)

OPERATING BUDGET - FISCAL YEAR ENDING JUNE 30, 1967
DETAILS OF PERSONAL SERVICE

Line No.	Title	Rate \$	No. of Empls.		Pay-Hours (Weekly Payroll)	Budget Allowance \$
			Full Time	Part Time		
<u>Station Department, Budget 31 (continued)</u>						
<u>Hourly Employees</u>		<u>Average</u>				
12	Collecting Agent	3,222	98		203,840	656,772
13	Extra Holiday Allowance				5,704	18,378
14	Overtime				50,570	162,937
15	Night Differential (189,084 hours) . .					5,673
16	Maintainer, Turnstile	3,673	2		4,160	15,280
17	Overtime				240	882
18	Railroad Clerk	2,923	4,149	(b) 18	8,642,712	25,262,647
19	Extra Holiday Allowance				216,872	633,917
20	Overtime				558,022	1,631,098
21	Night Differential (5,044,140 hours) .					151,324
22	Railroad Porter	2,800	1,145	(b) 10	2,388,544	6,687,923
23	Special Assignments		(c) 12		24,960	69,888
24	Extra Holiday Allowance				60,952	170,666
25	Overtime				89,332	250,130
26	Night Differential (1,432,068 hours) .					42,962
Total Hourly Employees			5,406	28	12,245,908	35,760,477
Total for Department			5,587	28	12,245,908	37,223,101
Less: Estimated Accruals & Rounding						64,101
Net Personal Service						37,159,000

OFFICE OF GENERAL SUPERINTENDENT-SURFACE, BUDGET 33

<u>Annual Employees</u>		<u>Actual</u>		
1	Clerk (Grade 5) X	10,850	1	11,050
	Salary Adjustments	200		
2	Clerk, Supervising (14)	6,950	3	20,730
	Annual Increments	6,470	2	
		360	1	
3	Clerk, Senior (10)	5,990	3	17,513
	Annual Increments	5,390 (5,413)	2	
		120	1	
4	Dispatcher, Chief Surface Line	11,729	2	22,881
		11,152	1	
5	Dispatcher, Surface Line	8,764	11	96,404

(b) for Summer Season, 7/1 to 9/15/66 and 5/15 to 6/30/67.
(c) 1 for Secretary's Dept.; 11 for Police Dept.

EXHIBIT

4

275

OPERATING BUDGET - FISCAL YEAR ENDING JUNE 30, 1967
DETAILS BY PROJECTS

Proj. No.	Description	Labor \$	Material \$	Other \$	Total \$
<u>LOST PROPERTY DEPARTMENT, BUDGET 30</u>					
1	Supervisory & Administrative				
	Operating Payroll for 2 employees	14,492			14,492
	Stationery, Printing & Office Supplies		750		750
	Free Transfers (Surface)		126,000		126,000
	Machine Tickets (Rapid Transit)		6,200		6,200
	Rockaway Special Refund Tickets		150		150
	Total - Supervisory & Administrative	14,492	133,100	--	147,592
2	Lost Property				
	Operating Payroll for 11 employees	68,660			68,660
	Printing (books; postcards & Lost Property forms)		2,000		2,000
	Bags & Locks		400		400
	Miscellaneous Expenses			75	75
	Total - Lost Property	68,660	2,400	75	71,135
	Total for Department	83,152	135,500	75	218,727
	Less: Estimated Accruals & Rounding ...	152	--	--	152
	Budget Allowance - Lost Property Department .	83,000	135,500	75	218,575

STATION DEPARTMENT, BUDGET 31

1	Supervisory & Administrative				
	Operating Payroll for 66 employees	431,831			431,831
	Stationery, Printing & Office Supplies		2,600		2,600
	Miscellaneous Expenses			1,700	1,700
	Total - Supervisory & Administrative	431,831	2,600	1,700	436,131
2	Procurement & Distribution of Supplies				
	Operating Payroll for 19 employees	132,070			132,070
	Stationery, Printing & Office Supplies		225		225
	Materials & Supplies		125		125
	Total - Procurement & Distribution of Supplies	132,070	350	--	132,420
3	Operation of Stations				
A - Supervision					
	Operating Payroll for 153 employees	1,243,227	--	--	1,243,227
B - Transportation of Revenue					
	Operating Payroll for 98 employees	843,760	--	--	843,760

EXHIBIT 4 (cont.)

OPERATING BUDGET - FISCAL YEAR ENDING JUNE 30, 1967
DETAILS BY PROJECTS

Proj. No.	Description	Labor \$	Material \$	Other \$	Total \$
<u>Station Department, Budget 31 (continued)</u>					
3	Operation of Stations (cont.)				
	C - Collection of Revenue				
	Operating Payroll for 4,100 (18) employees	27,381,074			27,381,074
	Stationery, Printing & Office Supplies		13,035		13,035
	Money Bags & Seals		43,000		43,000
	Replacement of 50 change booth stools		650		650
	Replacement of 50 Shur-lock Presses		325		325
	Purchase of 68 plastic station benches		10,540		10,540
	Washing & Repair of Money Bags			8,050	8,050
	Total - C: Collection of Revenue	27,381,074	67,550	8,050	27,456,674
	D - Cleaning & Elevator Operation				
	Operating Payroll for 1,149 (10) employees	7,174,977			7,174,977
	Cleaning Material		115,000		115,000
	Miscellaneous Expenses			2,750	2,750
	Total - D: Cleaning & Elevator Operation	7,174,977	115,000	2,750	7,292,727
	Total - Operation of Stations	36,643,038	182,550	10,800	36,836,388
4	Maintenance of Token-vending Machines				
	Operating Payroll for 2 employees	16,162	--	--	16,162
	Total for Department	37,223,101	185,500	12,500	37,421,101
	Less: Estimated Accruals & Rounding	64,101	--	--	64,101
	Budget Allowance - Station Department	37,159,000	185,500	12,500	37,357,000

OFFICE OF GENERAL SUPERINTENDENT-SURFACE, BUDGET 33

1	Supervisory & Administrative				
	Operating Payroll for 50 employees	422,940			422,940
	Stationery, Printing & Office Supplies		4,000		4,000
	Miscellaneous Expenses			825	825
	Total - Supervisory & Administrative	422,940	4,000	825	427,765
2	AFE's Required				
	Replacement of passenger automobile #345	--	2,500	--	2,500
3	Provision for Excess Employees	9,152	--	--	9,152
	Total for Department	432,092	6,500	825	439,417
	Less: Estimated Accruals & Rounding	92	--	--	92
	Budget Allowance - Office of Assistant General Superintendent-Surface	432,000	6,500	825	439,325

() denotes part-time employees.

EXHIBIT

5

NEW YORK CITY TRANSIT AUTHORITY

Allocation of Employees by Sections -- 1966-67

Station Department, Budget 31

Title	Total	Supervisory & Admin- istrative	Procurement & Distrib. of Supplies	Operation of Stations				Maintenance of Token Vend. Machines
				Super- vision	Trans- fer of Rev.	Collec- tion of Rev.	Clean & Elev Oper.	
<u>Annual Empls. --</u>								
Clerk (Grade 5) X	1	1						
Clerk, Supervising (14) ...	2	2						
Clerk, Senior (10)	4	4						
Clerk (7)	2	2						
Inspector of Service (Safes)	3		3					
Stenographer (8)	2	2						
Superintendent, Sr. (Station)	1	1						
Superintendent, Station ...	1	1						
Supervisor, Station	19	2	1	16				
Special Assignment	(a) 1			1				
Supervisor, Asst. Station ..	144	5	3	136				
Typist (7)	1	1						
Sub-total - Annual Empl.	181	21	7	153	--	--	--	--
<u>Hourly Empls.</u>								
Collecting Agent	98				98			
Maintainer, Turnstile	2							2
Railroad Clerk	4,149	45	4			4,100		
	(b) (18)					(18)		
Railroad Porter	1,145		8				1,137	
	(b) (10)						(10)	
Special Assignment	(c) 12						12	
Sub-total - Hourly Empls.	5,406	45	12	--	98	4,100	1,149	2
	(28)					(18)	(10)	
Total	5,587	66	19	153	98	4,100	1,149	2
	(28)					(18)	(10)	

(a) Coordinator of Cleaning.

(b) For Summer Season 7/1 to 9/15/66 and 5/15/67 to 6/30/67.

(c) 1 for Secretary's Department, 11 for Police Department.

Exhibit 6

Calculation of Maintenance Cost, Manhattan
Depot

Of the 81 employees, 51 are engaged in mileage-variable work. The titles and computation of real wages are:

Bus Maint. A \$3.64 hourly, \$7600 annual + 5% allowances

$$(\$380) = r_i (\text{adj.}) 1.09 + \$519 = w_i \$9183$$

Bus Maint. B \$3.653 hourly, \$7624 annual + 13 1/3 allowances

$$(\$1016) = r_i (\text{adj.}) 1.09 + \$519 = w_i \$9845$$

Bus Maint. Helper B \$3.015 hourly, \$6295 annual, + 16% allowances

$$(\$1006) = r_i (\text{adj.}) 1.134 + \$229 = \$8374$$

Multiplying w_i by # employees, $9183 \times 3 = \$ 27,549$

$$9845 \times 38 = 374,000$$

$$8374 \times 10 = \underline{83,740}$$

$$\text{Coin Box Maint.} + 1 \quad +10,389$$

$$495,679$$

Materials (omitting garage expenses,
cleaning material, and fuel
costs)

$$\underline{69,300}$$

$$\$ 564,979$$

Dividing by 4,321,000 miles we get 13.05¢ per mile
(compared to 21.4¢ budgeted shop cost or 23.64¢ total
allocated cost).

EXHIBIT 7

Acceleration and Steady Motion (Top Speed) Power Consumption
Assuming Level Track for All R-Type Equipment: 23

<u>Average for:</u>	(All Nos. Amperes per Second*)			
	IRT		IND-BMT	
	<u>Loaded</u>	<u>Empty</u>	<u>Loaded</u>	<u>Empty</u>
First 12 Seconds	385	310	410	335
12-20 Seconds	310	250	330	270
20-28 Seconds	245	200	260	215
28-36 Seconds	190	160	200	170
36-44 Seconds	140	130	145	130
Max. Speed (45-50 mph)	100	100	100	100

*Per motor pair, of which there are two per car.

Stationary or Coasting Costs in Kilowatts/Hr./Car:

Motor Generator	.4	.4
Lighting	1.35	1.8
Compressor	.25	.25
Sub-Total	2.00	2.45
Heating	11.25	15.00
Total	13.25	17.45
Fans	N.A.	N.A.

Thus to calculate the power consumption, first calculate the amp-secs. consumed according to the characteristics of the route section in question, multiply by .6 to convert amp-secs. to kw-secs., double to get the rate per car, divide by 3600 to convert kw-secs. to kw-hrs., add the stationary costs and divide by the mileage traversed to obtain the actual power cost per car mile.

EXHIBIT 7 (continued)

It would be advantageous to reduce these calculations by making up a table for the given system (see Exhibit 8).

Exhibit 8

Cumulative totals, kw-hrs. consumed in acceleration

Time Elapsed	IRT				IND-BMT			
	Empty	SetLd	50% Stn	Load	Empty	SetLd	50% Stn	Load
0-20 sec.	1.905	2.021	2.138	2.365	2.059	2.173	2.288	2.520
21	1.972	2.091	2.212	2.446	2.131	2.248	2.367	2.607
22	2.039	2.162	2.286	2.528	2.202	2.323	2.446	2.693
23	2.105	2.232	2.360	2.609	2.274	2.399	2.525	2.780
24	2.172	2.302	2.434	2.691	2.346	2.474	2.604	2.867
25	2.239	2.373	2.509	2.772	2.417	2.549	2.683	2.953
26	2.305	2.443	2.583	2.854	2.489	2.625	2.762	3.040
27	2.372	2.514	2.657	2.935	2.561	2.700	2.841	3.127
28	2.439	2.584	2.731	3.017	2.632	2.775	2.920	3.213
29	2.492	2.640	2.789	3.080	2.689	2.834	2.982	3.280
30	2.545	2.696	2.848	3.143	2.745	2.893	3.043	3.346
31	2.599	2.752	2.907	3.207	2.802	2.952	3.105	3.413
32	2.652	2.808	2.965	3.270	2.859	3.011	3.167	3.480
33	2.705	2.864	3.023	3.333	2.915	3.070	3.228	3.546
34	2.759	2.919	3.082	3.397	2.972	3.130	3.290	3.613
35	2.812	2.975	3.140	3.460	3.029	3.189	3.352	3.680
36	2.865	3.031	3.198	3.523	3.085	3.248	3.413	3.746
37	2.899	3.075	3.243	3.570	3.128	3.292	3.459	3.794
38	2.942	3.119	3.288	3.616	3.171	3.337	3.505	3.842
39	2.985	3.163	3.333	3.663	3.214	3.381	3.550	3.891
40	3.029	3.208	3.378	3.710	3.257	3.426	3.596	3.939
41	3.072	3.252	3.423	3.756	3.300	3.470	3.642	3.987
42	3.115	3.296	3.468	3.803	3.344	3.515	3.688	4.036
43	3.159	3.340	3.513	3.850	3.387	3.560	3.734	4.084
44	3.202	3.384	3.558	3.896	3.430	3.604	3.780	4.132

each additional sec. = .0333 kw-hrs. at maximum speed

Armed with plots or checks of the number of seconds of acceleration, maximum speed and coasting-braking-or standing between and in each station, the above table, with the addition of the stationary in-service costs will yield a more exact picture of power costs per car mile, although ignoring certain variations such as grades.

CHAPTER VII

ANALYSIS OF STATE VARIABLES: APPROPRIATE
INITIAL DIRECTIVE CRITERIA AND APPLICABLE
ALTERNATIVES FOR CHANGE .

CHAPTER VII

Analysis of State Variables: Appropriate Initial Directive Criteria and Applicable Alternatives for Change

Introduction

In Chapter IV, a model of Schedule and Route Planning was set forth. Making use of the hypotheses on demand developed in Chapter V, and the data on costs presented in Chapter VI, this chapter will elaborate on the decision-making phase (Part II) of the model. Using the data on cost and demand, the process of evaluating alternative changes will be illustrated with examples for each State variable.

The State variables as defined in Chapter IV describe the existing (and changed) state of the transit service. The State variables are Frequency, Speed, Comfort (Scheduled Load), Actual Load, Actual Headway, Actual Running and Terminal Time, Work Program, Mileage, Demand, Transfer Volumes, and Unserved Trip Patterns and Activities. One or more "Initial Directive Criteria" must be applied to each State variable to determine whether that variable should or should not be changed, according to the terminology of the model.

Thus, in adopting a systematic approach to the scheduling of its routes, a transit system will first want to

decide on a set of Initial Directive Criteria (i.e., measures of adequacy) for each State variable. These Initial Directive Criteria (IDC) will in each case be sub-objectives designed to come closer to the larger system objectives already decided on. This chapter will, for each State variable, identify and quantify one or more IDC, and will use these criteria (along with data from Chapters V and VI) to generate and evaluate alternative changes in the "control" variables (Headway, Running Time, Terminal Time, Vehicles, Route and Control/Supervisory) designed to bring the State variables in line with the objectives of management (as reflected in the IDC).

Frequency of Service

This refers to scheduled mean headway. Foremost among the IDC for this variable is: Is this the best headway, or would a greater or lesser headway be closer to satisfying the system objectives? If the system objective is giving the best service possible at a break-even or better point, the procedure of generating alternatives would resemble the example in Chapter IV. Alternatively, the objective may be to earn a fixed percentage profit to cover overhead, or to tolerate a deficit if at least x people ride the bus per trip.

For each possible objective, the only way to find out if the frequency is satisfying the objective is to range over a number of different headways and compute the results on whatever costs and revenues are being considered. There is no way of knowing if the present frequency of service is the best, no matter what the objective, unless the effects of alternative frequencies are simulated.

Frequency is directly transformed by changing the Control variable "Headway." The effects of each alternative Headway would not, however, be confined to the State variables Frequency, Work Program, Mileage and Demand (which further transform into the Cost and Revenue measurements necessary to evaluate the extent to which the change meets the stated objectives). The Control variable function for Headway is $\text{Headway} = c(\text{Running Time} + \text{Terminal Time})/\text{Vehicles}$ (see Chapter IV). This means that to change Headway either Running Time, Terminal Time or the number of vehicles must be changed, singly or in combination. In addition, Headway itself has other effects, for example on Load--which in turn may affect Actual Load--and this too may be significant.

Thus there is a choice of not only what Headway is best, but also of what is the best method of changing the Headway. Carefully explored, such alternatives may show, for example, that in a given case using an added vehicle to

increase the Running Time or Terminal Time with the same Headway, rather than using an added vehicle to decrease the Headway, will be the better move.

Because of these interrelations between State variables, either directly or via the interlocking effects of the Control variables, it may also be that although Headway (i.e., Frequency) might be found optimum for the desired objective(s), an examination of some other State variable will reveal an inadequacy best corrected by or permitting a re-evaluation of changes in the Headway. For example, in looking at either Speed or the Terminal Time component of Work Program, it may be found that there is excessive Terminal Time, and that the only cost of decreasing the Headway within a certain range is the mileage cost. Under these altered circumstances, the optimum Frequency may no longer be at the previously decided point.

The "best" or "optimum" (or simply, a "better") Headway in terms of the stipulated cost-Revenue balance (or any other criteria desired, including maximum ridership without regard to cost) will not be the only IDC applied to Frequency. Two other IDC should be: Minimum or maximum desired Headway, and scheduled connections. In the first case, management may decide that no line should operate on greater than a twenty-minute Headway, regardless of any other criteria. This

would be a service-to-the-public kind of objective not amenable to any rational testing. It would require reducing headways on any lines presently operating on greater headways, as was done for "owl" (1:00 to 5:00 AM) subway service in New York in 1957.

The scheduling of connections between feeder bus and rapid transit lines, or between two bus or subway lines where large transfers take place, may often require adjustments to the "optimum" headway. The adjustment would be made by either reducing or increasing the headway of one line to match the headway, or some multiple of the headway, of the connecting line. In addition to this alternative, the headway of the other line might be adjusted; or both may be changed. With data on the effects on demand of "missed" vs. scheduled connections, a new "optimum" point could be calculated.

This new optimum point may not be the same as the optimum without considering connections, because the increased NOC (see Chapter IV for discussion of NOC = Net Operating Contribution) previously achieved may be offset at the uniform headway by the increased cost of additional service on the connecting line, if the headway on the connecting line is decreased. Thus where several feeder or connecting lines are involved, the sum NOC of all the lines

would be the relevant IDC to be maximized under the general objective of maximum return.

As an example to illustrate the above discussion of Frequency, consider the case of the three bus feeder lines terminating at Forest Hills-Arborway on the Everett to Forest Hills MBTA line in Boston on Sunday (see Figure 1). These three lines operate to Cleary Square via Hyde Park Avenue; to Dedham line via Washington Street; and to Charles River Loop via Center and Spring Streets, on frequencies of 20, 20 and 25 minutes respectively.¹ Let us assume a system objective of maximum service at maximum NOC.

Calculations using the method illustrated in Chapter IV, the relevant regression equation for Sunday revenue ($P = 191.5 - 2.71 H$),² and an assumed marginal contribution of 23¢ per revenue passenger,³ the alternative cost revenue comparisons (based on costs developed in Chapter VI) show the optimum headway for each line (maximum NOC) to be just what is now being run: 20, 20 and 25 minutes respectively (see Table 1 and Figure 2). At these points, any increase or decrease in frequency would result in a net loss (negative marginal NOC). Within the range of headways examined (see Table 1) they are global optimums.

The rapid transit line runs at a 12-minute headway, however. If coordinated schedules are another IDC, then

FIGURE 1

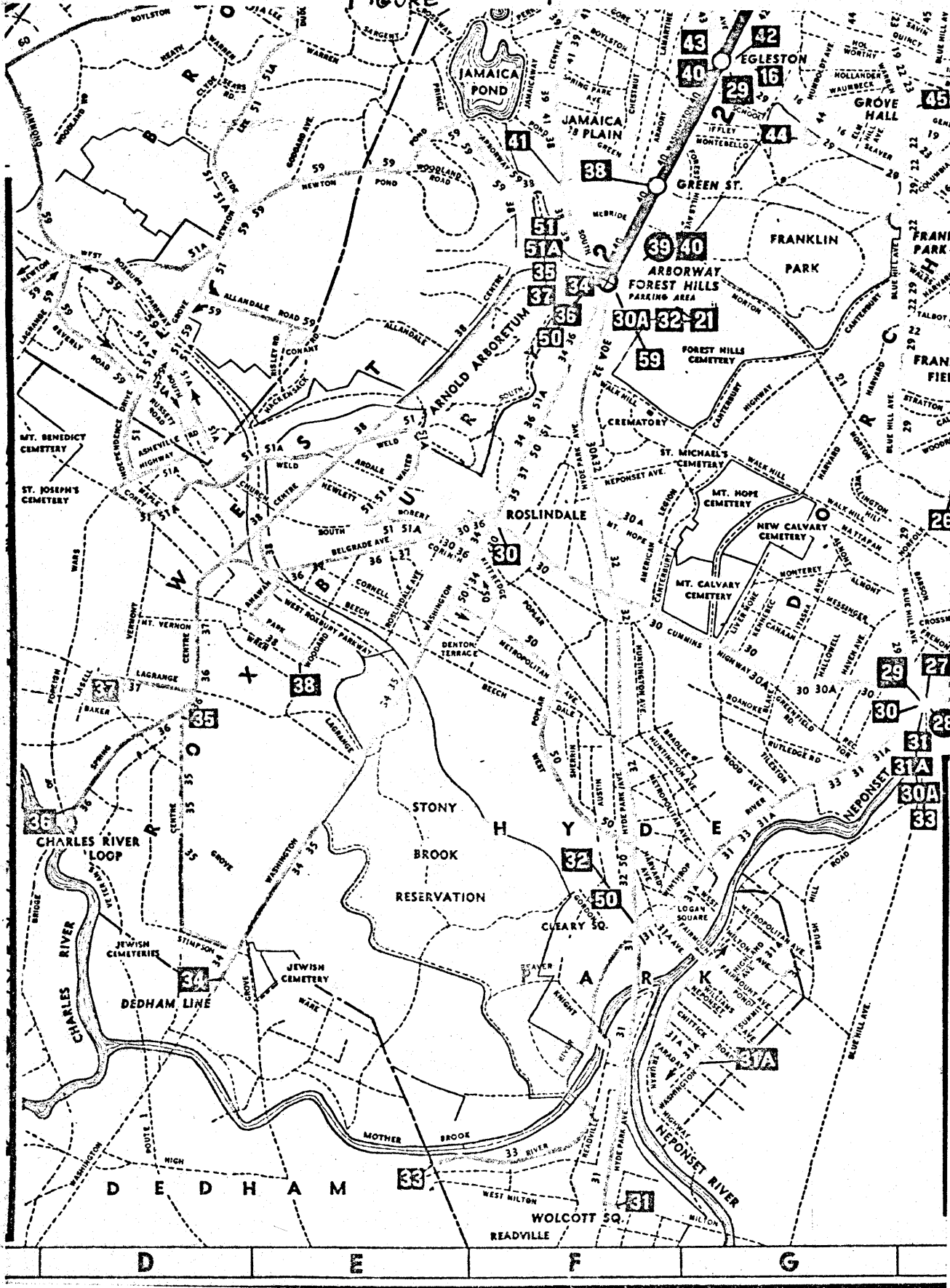


Table 1

Net Operating Contribution for Alternative Headways,
Sunday

Head- way	Passen- gers per 1000	Line 32*			Line 34*			Line 36*		
		Pass. Rev.	Cost	NOC	Pass. Rev.	Cost	NOC	Pass. Rev.	Cost	NOC
6	175	752	908	(-156)	625	1003	(-378)	897	1171	(-274)
7 1/2	171	736	734	2	611	810	(-199)	877	945	(- 68)
→10	164 1/2	707	559	148	587	618	(- 31)	843	720	143
11	162	697	517	180	578	571	7	830	667	163
→12	159	684	475	209	568	525	43	815	612	203
15	151	650	398	252	540	438	102	774	566	208
20	137	590	343	(257)	490	378	(112)	702	478	224
22	132	568	328	240	472	363	109	676	458	218
24	126 1/2	545	344	201	452	366	96	648	405	243
25	123 1/2	531	329	202	437	350	87	633	388	(245)
30	110	474	273	201	393	301	92	565	352	213
33	102	439	259	180	364	285	79	523	333	190
35	96 1/2	415	245	170	345	270	75	494	316	178
36	94	404	238	166	335	263	72	481	307	174
40	83	357	203	154	296	224	72	425	261	164

TOTAL NOC Now 614

 At Optimum 614

 At 20 min. 593

 At 24 min. 540

Extra cost of going

to 10 or 11 min. Hwy. on Rapid Tnst.

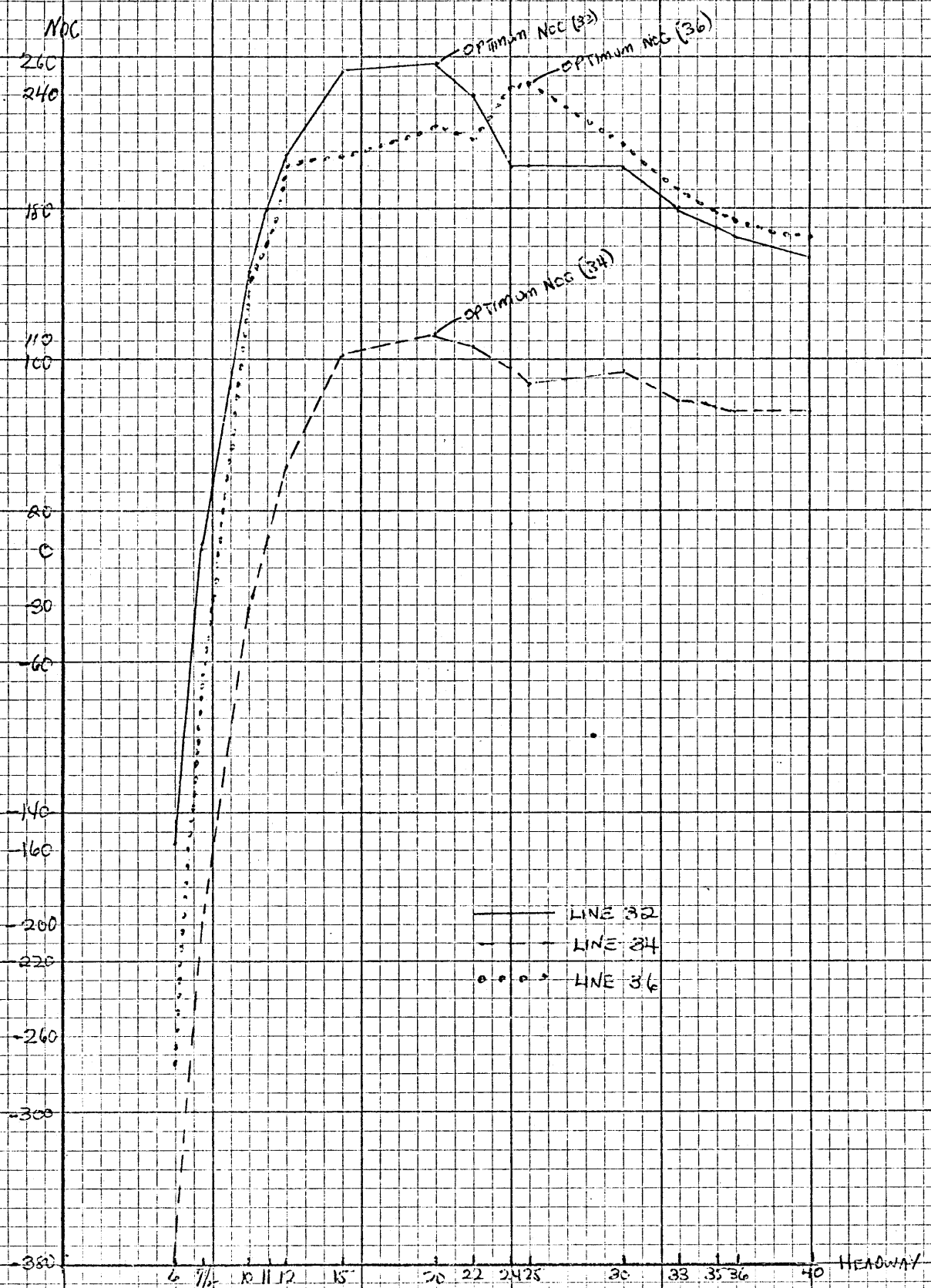
Extra crew 84

Mileage 82

166

* 1967 Service Areas: Line 32 18,655
 34 15,500
 36 22,230

FIGURE 2
NOC vs. HEADWAY, SUNDAYS, 3 LINES



clearly the above headways are no longer optimum. Going to an 11, 10 or 7-1/2-minute headway on the rapid transit line would cost more, in terms of NOC, than going to a 24-minute headway on all three bus lines (see Table 1). It appears that any adjustment to coordinate the headways would reduce NOC from the optimum level originally calculated (without scheduled connections being an IDC), and that a uniform 24-minute headway on the bus lines reduces NOC the least.⁴ However, data on how such coordination affects demand might show that this, or some other alternative, actually increases NOC.

The frequency of service, i.e. the scheduled headway, need not be uniform over a given route. This introduces an additional alternative into consideration. Some vehicles can be "shortlined," that is, turned short of the full length of the line at an intermediate terminal. Thus a service may be defined by more than one headway, according to the portion of the route involved. Where service required to meet a load, or calculated as having maximum NOC, serves an outer portion of route with only a small part of the total service area, this would be desirable. It would also be, and is, effectively used on routes with frequent service in peak hours. There is no a priori way of judging its value, however, without again calculating the alternatives and their effects.

In the previous example, line 34 to Dedham line has three-quarters of its service area in the first half of the route length. The doubling of the previously determined optimum headway over this half of the route, from 24 to 12 minutes, would raise NOC by \$1.50 for the day. This is a case where at least on paper the introduction of a shortline makes more frequent service viable where the same service the length of the line would cost the company more. The example is a convenient one, although in reality part of the service area affected is served jointly by this line and the Charles River Loop line (#36), and coordinated schedules would provide 12-minute service to this portion at no extra cost, leaving only half the service area of line 34 to benefit from the shortline--and, consequently, making the shortline unwise.

There are other alternative solutions involving the manipulation of other State variables; these will be illustrated as each State variable is discussed. The above calculations were based only on manipulation of the variable "Frequency."

Speed

The State variable Speed is an absolute measurement, looking at the scheduled speed of a line (but not the

performance speed in comparison to the scheduled speed: this is the purpose of the State variable Actual Running Time). Thus the appropriate IDC would be either a minimum acceptable speed in miles per hour, a maximum acceptable speed (the legal speed limit, for example), or a speed consistent with the movement of non-transit traffic on the street.

Two Control variables can be altered to effect changes in Speed if any of the IDC are not met. One is Running Time; but before any change is made in Running Time, the State variable Actual Running Time must be examined. Clearly if the Actual Running Time corresponds to the scheduled Running Time, any change in Running Time to affect the Speed will be a change on paper only, and will not accomplish its intended effect in actual practice. If, however, it is discovered that inadequate or excessive Running Time is the cause of high or low scheduled Speed, then Running Time can be used to change the Speed by changing the appropriate number in the equation $\text{Speed} = \text{Route Mileage} / \text{Running Time}$.⁵

Route is the other Control variable affecting Speed. A low speed may be due to traffic congestion on a particular street, or to overly close spacing of stations on a rapid transit line. In the first case, diversion of the route during the hours of street congestion to a nearby parallel street (or off a crowded expressway onto a local street) may

be a solution if the existing route does not pick up or discharge many passengers on the affected portion. In the second case, discovery of an inadequate speed may prompt an investigation of the effects of closing some of the stations at certain hours, or of running express service.

Route mileage can be lengthened or shortened to achieve the desired speed, where terminal time and not running time is the excessive component. This would be done when a given headway, for reasons such as coordinated connecting headways, is not optimum for the running time; that is, requires excess or tight terminal time (see example).

Here again, the secondary relationships between the variables bear consideration. If Speed is to be altered by changing Running Time, secondary effects may be felt in Demand or in Actual Running Time (see discussion under that heading). In addition, a change in Running Time will require a change in either Headway, Vehicles, or Terminal Time.⁶ If Running Time is to be reduced with no increase in Terminal Time and no decrease in Vehicles, then Headway must be reduced and this will in turn change the State variable Frequency.

Thus there exist alternatives not only of ways to change Speed (via route or running time changes), but also of ways to change the relevant Control variables. Each will in

turn affect the existing balance of the system State and may call for changes in several State variables to achieve a new optimum point. Thus each must be evaluated.

Referring again for an example to the three main feeder lines serving Hyde Park, Roslindale and West Roxbury on Sundays in Boston (Figure 1), an analysis of the minimum scheduled round trip running times (including terminal times) and the round trip mileage per route⁷ shows average speeds of 11.9, 12.1, and 10.9 miles per hour respectively. There may well be good reason for the lower speed on the Charles River Loop line, but let us assume that none is found, and that lowering the round trip minimum from 48 to 44 minutes raises the average speed from 10.9 to 11.9 miles per hour.

Table 2 and Figure 3 show the revised calculations with labor costs revised to reflect the new running times. Optimum headway is now 15, not 25 minutes. Note that at a 15-minute headway in Table 2, the cost has been increased by \$102 over the 25-minute headway in Table 1, while revenue has increased by \$141. This same \$39 gain is reflected in comparing the respective NOC's.

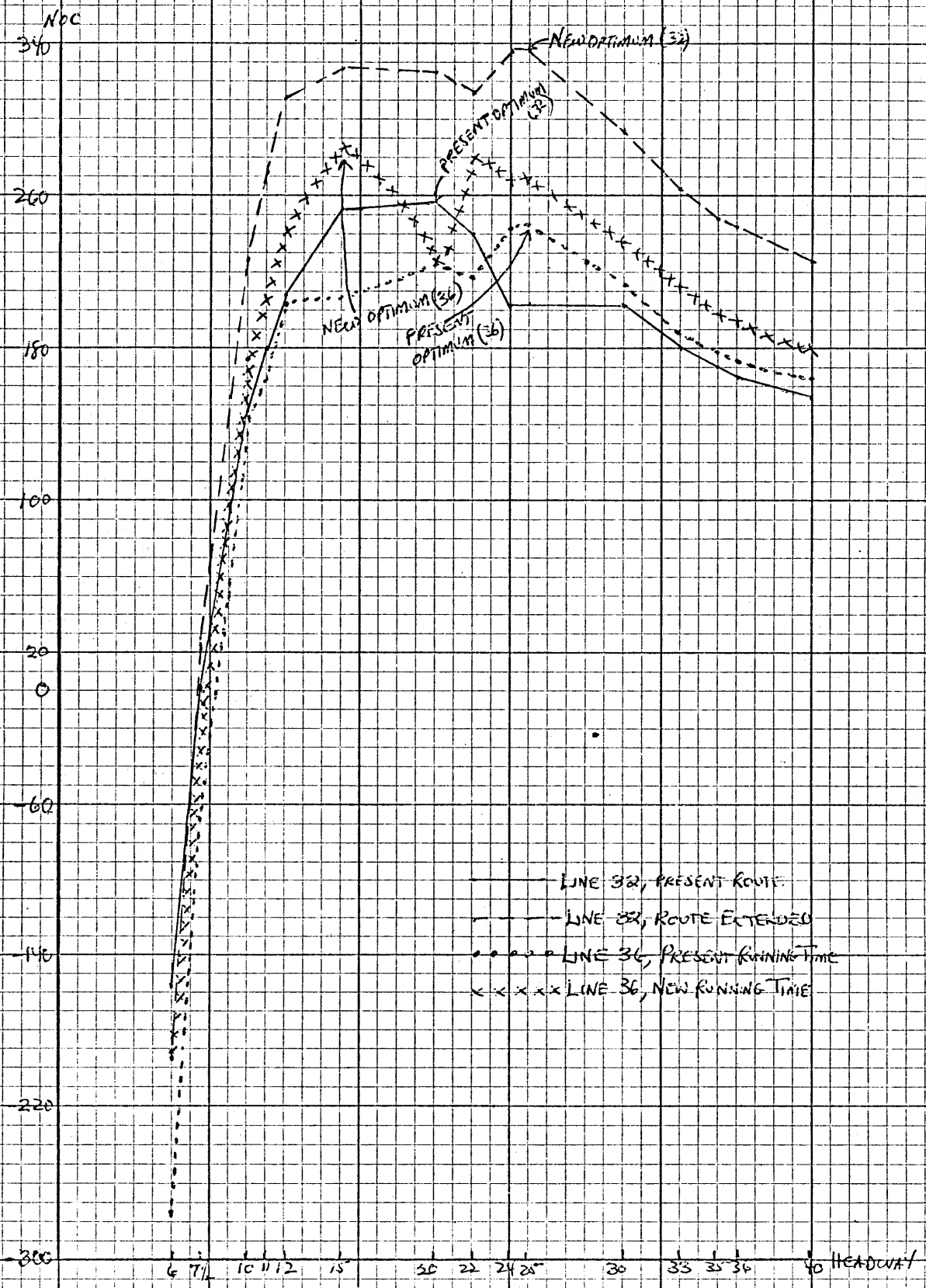
To illustrate the manipulation of Route to affect Speed, consider the line from Clear y Square, under the constraint of coordinated headways. The scheduled round trip time is 48 minutes, 13 more than the permissible minimum,

Table 2

Recalculation of Table 1, Line 36, New Running Time

<u>Headway</u>	<u>Rev.</u>	<u>Cost</u>	<u>NOC</u>
6	897	1094	(-197)
7 1/2	877	884	(- 7)
10	843	674	169
11	830	624	206
12	815	573	242
15	774	490	(284)
20	702	478	224
22	676	396	280
24	648	379	269
25	633	363	270
30	565	329	236
33	523	312	211
35	494	296	198
36	481	287	194
40	425	245	180

FIGURE 3
EFFECT OF NEW RUNNING TIME AND ROUTE EXTENSION
ON NCC VS. HEADWAY



reducing average scheduled speed to 8.6 miles per hour. An extension of this line into the Fairmount section of Hyde Park, presently unserved on Sunday, would add over 7,000 people to the service area,⁸ and raise average speed to 12.9 miles per hour. Table 3 and Figure 3 show the new optimal headway to lie at the desired 24 (or 25) minutes, and show an improvement of \$135 in NOC at the coordinated 24-minute headway.

Other extensions are possible as alternates; the choice of which area to serve is considered under the State variable "Unserved." The Dedham line via Washington Street bus line could also be extended either via Washington Street to VFW Parkway or via Centre and Grove Streets. The effect would be similar.

The use of a 23¢ fare in these calculations assumes that the marginal rider attracted or lost is lost not only to the bus line but to the system in its entirety. The rise and fall of NOC thus indicates how much revenue would be added or subtracted for a given change. Since the changes considered are on the bus lines only, it seems fair to allocate any additional revenue entirely to the bus line, when no change is required in service on connecting rapid transit or surface lines. The total revenue accruing to the bus line on the basis of ten-cent fares, however, is throughout Tables 1,

Table 3

Recalculation of Table 1, Line 32*, Route Extension

<u>Headway</u>	<u>Rev.</u>	<u>Cost</u>	<u>NOC</u>
6	1070	1262	(-192)
7 1/2	1042	1018	24
10	1004	776	228
11	989	718	271
12	971	660	311
15	923	596	327
20	837	512	325
22	806	491	315
24	772	436	336
25	754	417	(337)
30	672	379	293
33	622	359	263
35	589	340	249
36	574	330	244
40	507	281	226

* New Service Area 26,455

New Total NOC	At Optimum	694
	At 20 min.	661
	At 24 min.	675

2 and 3 less than the variable cost of operation.

The real effect of maximization of NOC is thus, in these examples, to minimize loss rather than maximize profit (at a ten-cent fare). For this reason, the IDC of maximum service at break-even or better is not relevant to the examples considered; the break-even point is never reached.

Although the above examples do not readily lend themselves to the alternative of express service, this is one other way of altering the Speed of a line. It is essentially a variant of the use of Running Time to increase Speed, in this case by by-passing a given number of stops and thus reducing the scheduled Running Time. Express service may often be provided in conjunction with a shortline (see page 292), with the full route-length vehicles operating express in the area of the shortline operation.

Express service may also be desirable even where no significant time savings is effected, if it segregates a large point to point movement without adversely affecting the frequency of regular service. The psychological advantage of express service to the passenger, in terms of both the by-passing of stops, and the omission of the discomfort associated with constant starts and stops, is probably as important as the time savings in determining the demand for a

service. While insufficient data were available in Chapter V for statistical analysis of this factor, the application of the method of schedule analysis being proposed throughout this thesis would eventually require such information in order to consider this alternative intelligently.

Load

Load is the State variable representing the load factor in the vehicle, a ratio of either passengers/vehicle to seats/vehicle or passengers per vehicle to total capacity/vehicle. Presently, as described in Chapter II, the scheduled load factor is an average over a time period of from 15 minutes to an hour; and the system criteria for load factors are not consistently applied.

The IDC for the load factor on any given line would be the extent to which the load factor meets some stipulated policy factor. The management should decide on what kind of loads they are willing to tolerate, depending on the time of day, kind of riding, etc., and apply this standard uniformly. If the management is willing to settle on such a criterion, there is no point in applying it haphazardly. Exceeding the desired load factor would militate against whatever values the management sees in their objective; operating at less than the specified load would be a waste of resources.

There are two larger goals that management can consider in deciding on what load factor they wish to maintain. One is that of NOC; the load factor should be decreased so long as the marginal NOC is rising. This method will not always guarantee, however, a load factor providing seats for all in non-rush hours, which might be an objective of the system. For example, an optimum headway calculation for the Arlington Heights to Harvard Square line on Sunday, in the same manner as described under the discussion of Frequency in Chapter IV, shows the maximum NOC at 22 minutes. (Table 4 and Figure 4.) However, the load factor at a 22-minute headway⁹ is 76 passengers per bus. In order to achieve approximately a seated load, twice as much service must be run, at a lower NOC. An 11-minute headway is, in fact, the present service.

The other major goal would be to provide seats for all passengers, or a maximum load factor, depending on the time of day. There are several ways of approaching this criterion. Presently an average load factor is used as a measuring stick. This guarantees that no matter what the load factor: 1.0 (seats for all), 50% standees (1.5 or 150% load), or any other number: the passenger will not experience the stipulated factor. This is because the ratio of passengers per seat as an average over a given time period does not take into account the variation in loading arising from variations in

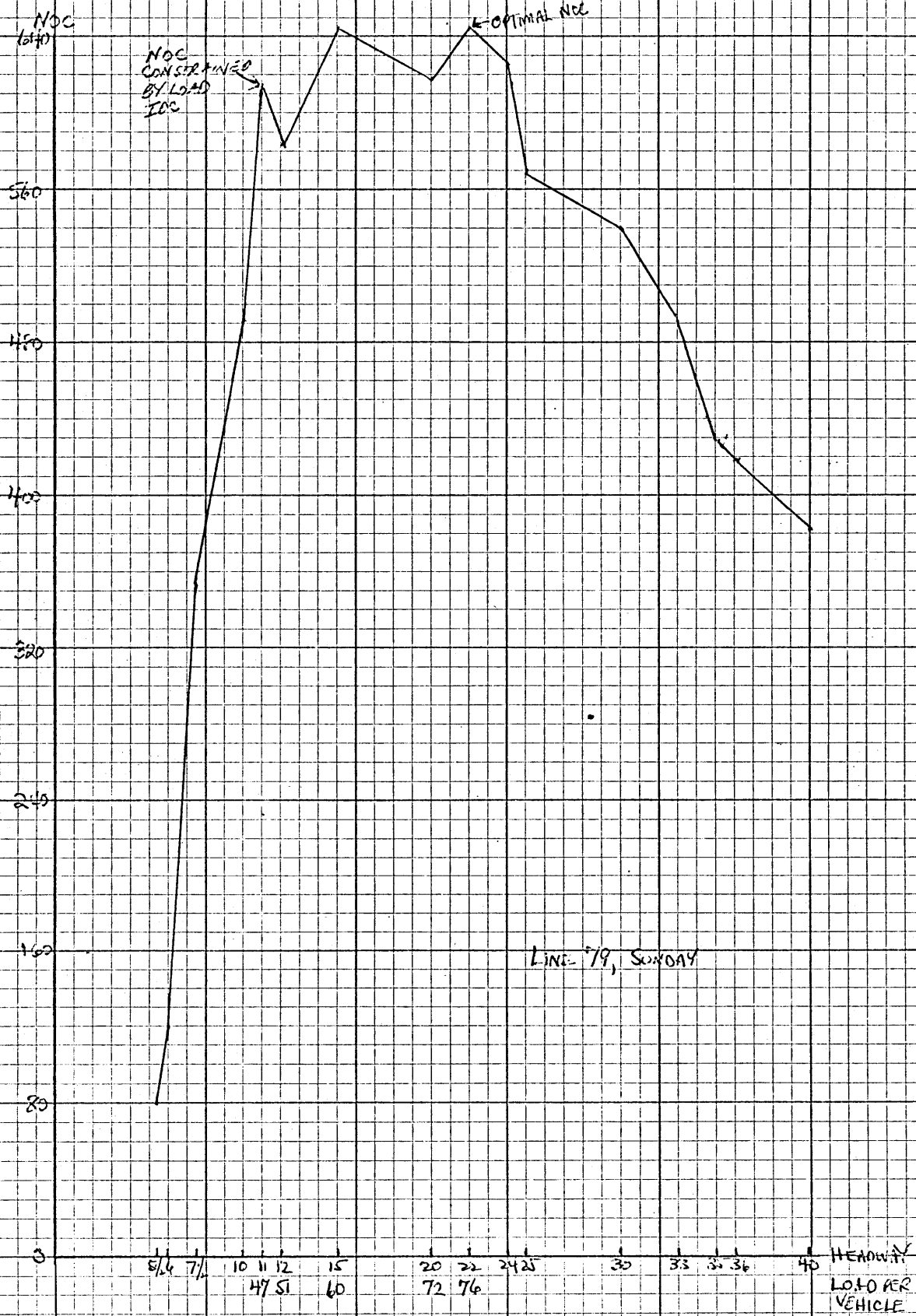
Table 4

Net Operating Contribution Constrained by Load
Factor Line 79, Sunday*

	<u>Pass. Rev.</u>	<u>Cost</u>	<u>NOC</u>	<u>Avg. Load</u>
5 1/2	1545	1465	80	
66	1530	1410	120	
7 1/2	1495	1139	356	
10	1440	948	492	
11	1418	803	615	47
12	1390	806	584	51
15	1320	676	644	60
20	1200	581	619	72
22	1155	510	(645)	76
24	1108	533	625	
25	1080	510	570	
30	963	423	540	
33	892	401	491	
35	845	415	430	
36	822	403	419	
40	726	344	382	

* Service Area 38,000

FIGURE 4
OPTIMAL NOC CONSTRAINED BY LOAD FACTOR



headway and fluctuations in passenger traffic and the distribution, in rapid transit, of loading over the length of the train.

There are two basic kinds of disturbances in the even flow of passengers and vehicles. The first is random, due to diverse causes not under the control of the operating transit company--traffic congestion, weather, the laws of chance. To the extent that these variations are purely random within a homogeneous time period,¹⁰ a poisson table would be a useful tool for predicting the frequencies of deviations.¹¹ That is, if an average arrival rate of 40 passengers per given time period is scheduled for a 45-seat bus, this table says that one out of every three buses will have standees, and that fully ten per cent of the buses over time will have load factors over 150%.

This is not merely a hypothetical situation. A typical MBTA survey, for example, shows just such a pattern of variation, due to variations in headway and passenger arrivals, even in a short period of a few hours. A four-hour sample of the inbound Grove Hall buses at Dudley station in Boston on Saturday, June 2, 1962, shows 19 buses with 775 passengers, or 41 per bus.¹² This average is constant through the four hours. Six of the buses have standees; of these, one had 75 passengers, well over the 150% load rate. (During this same

period outbound, two buses had loads over 67 passengers.)

The implications of this kind of variation are clear. Management must first decide not simply what load factor to use as an IDC but what percentage of the passengers they wish to experience the stipulated load factor. In the above example, 360 of the 775 passengers, or $46\frac{1}{2}\%$, rode on buses with standees (9 to 30 standees). It is not likely that the passengers on this route believed the service provided seats for all.

Where a seats for all policy is adopted, it should be clear from the above that the average scheduled load must be considerably less than a "seatedload." It may be desirable to derive this required reserve from observations on the individual lines concerned, developing what Doolittle calls a "diversity factor"¹³ for each line, rather than use the poisson tables.

The second kind of disturbance is one caused either by predictable influences on passenger traffic: a late-store opening night, a ballgame, a heavy snowstorm, a school holiday, etc.; or by controllable deviations in operation, such as a late vehicle. A variation of the latter kind would be the uneven distribution of passengers over a rapid transit train, again a fluctuation within the control of the management.

The operation of the same schedule for varying conditions of passenger demand cannot possibly enable uniform adherence to whatever standard management stipulates for loading. Yet major systems such as New York pay surprisingly little attention to such variations; annual cordon counts, for example, may be taken on some lines on late shopping nights and on others on normal evenings. Further, a different pattern will be followed each year from line to line. Similarly, average loads are scheduled by train in New York, although the variation in loading throughout the train may be substantial; middle cars will often have a 200% load factor while end cars have seats at the peak point.¹⁴

If the management is interested in applying whatever set of objectives they feel is best consistently, and not haphazardly, then it becomes important to distinguish various kinds of demands in the same way that the data on demand collected must be classified and analyzed (see Chapter V.). The specific conditions influencing demand will determine, from line to line, the need for separate schedules to maintain the desired load factor. A line serving a major university and linking it to one or more other university or entertainment areas may experience a sharp increase in usage on Friday and Saturday nights;¹⁵ this same line may experience a surge of riding on the day before a holiday, and

sharply reduced riding during the holiday. None of these trends would be seen on a residential feeder line.

Similarly, habitual deviations in service (discussed further under Actual Running Time and Actual Headway) or the dispersal of passengers through a train are factors which the transit company can and should control if it wishes to be consistent in the application of its objectives. Blaming the higher load factors in the center cars on the passengers' unwillingness to disperse through the train accomplishes nothing. The tendency to cluster towards the center of the train is due to the placement of station entrances and exits. The solution, if the scheduled average load factor is desired in each car, and not merely on paper, is to run shorter trains more often.¹⁶

Such a solution will, in cases where additional manpower is not available (see discussion of Work Program), cost more. The management may decide, based on what information is available to them on the sensitivity of demand to the probability of finding seats, that it would be better to run longer trains with standees in the center cars. What is important, and sought for as the outcome of the application of the method proposed herein, is that a clear, measurable evaluation of these alternatives is possible, and that the state of the loading in the trains is pictured more

realistically for the decision-makers.

Finally, in addition to deciding on what load factor is a desirable objective under varying conditions, and on what percentage of passengers should experience this load factor, the IDC should also address itself to the question of duration of the stipulated load: that is, for how long or over what length of route and time is management willing to operate the load factor. Obviously a maximum load which occurs for only a few minutes can be set at a higher rate than one which lasts for a major part of the journey, from the passenger's viewpoint. This same consideration should apply to the operating company's thinking.

Doolittle notes that

In order to furnish ten passengers with seats for a mile trip, it may be necessary to run a car with seats for forty passengers five miles. The two hundred seat miles furnished for ten passengers miles may impose a burden on the service that is not to the best interest of the patrons as a whole.¹⁷

He thus suggests that the relevant figure to be considered is not seats and passengers but seat miles and passenger miles. There is, however, an alternative solution to this problem. While it may be unwise to provide 200 seat miles for ten passenger miles, a more equitable load distribution may be achieved by the use of shortlines. In other words, it may not be necessary to run the additional seats the full

length of the line.¹⁸

In deciding on the load factors to be scheduled, it would be well for the management to be aware too of the way in which diverse but less measurable factors affect the passenger's perception of an adequate level of comfort. In the same treatise quoted above, Doolittle summarizes the results of surveys in Milwaukee and Cleveland which showed that the maximum load factor passengers would tolerate

. . . was thought to be greater in winter than in summer; for a short ride rather than for a long one; when the majority of passengers are male rather than female; professional men rather than laborers; and teamsters rather than tannery or glue factory workers. (p. 207)

Before closing the discussion of loading, it should also be noted that heavy loads (high load factors) may be a cause of higher accident rates, and thus of claims for injury and damages. Statistical investigation of this effect would probably be most fruitful. It is clear that there is a greater hazard of slipping, pushing, etc. in a crowded vehicle or on a crowded platform. In addition, it is harder for a bus driver to see the rear exit in a crowded bus.

The latter was probably a prime reason for the high rear-door accident rate (doors closing on exiting passengers) that prompted a number of transit systems to equip their buses with passenger-operated rear doors--although the

passengers emphatically dislike these, particularly the kind which require pushing open and not merely stepping on a tread.

Actual Headway, Running Time and Terminal Time

Scheduled Frequency and scheduled Speed are controlled, as discussed earlier in this chapter, by scheduled headway and scheduled running time. However, a measure is needed of the actual performance of the schedule on paper, since the headway and running time will vary for reasons similar to those described above in discussing variations in actual loads.

If the scheduled running time is either too loose or too tight, measurements of the actual running time will reveal this. At present, where the running time in New York or Boston on subway or bus lines is tight in rush hours, resulting in erratic headways (due to the lack of recovery time along the line) and occasionally late terminal departures (where terminal time is insufficient to recover time lost along the line), there is a tendency to not adjust the running or terminal time because of the additional cost; similarly, where running time is too loose in the non-rush hours, it is often not tightened because of the lack of identifiable cost savings.

In the rush hour, or in any situation of congestion, the loads on the vehicles are sufficiently heavy so that perturbations in the scheduled running time will affect headway and load adversely, as described in Chapter II. Chapter V discusses the effects of such disturbances in service on demand and strongly suggests that the variation in revenue may often be a relevant consideration.

For example, the data on the Harvard to Dudley bus line of the MBTA in Chapter V¹⁹ show a daily revenue loss of \$150 (1,500 passengers x 10¢). It would be difficult to ascertain how many of these people chose to use the subway stations along the line instead; and conversely how many reverted to other modes who formerly used the line as a feeder to other bus or subway lines. Assuming that these effects balance out each other, the loss of \$150 a day is self-contained and the result of the less reliable headway due to the shortened running time. In reducing the running time, no mileage was saved, but three drivers and three buses in the morning and evening peak hours were saved.

Observations by the author indicate that in the morning, restoring one bus would be sufficient, but that in the evening peak, all three should be returned to achieve the former reliability of service.²⁰ This would require one bus,²¹ two straight run drivers (available for additional work in non-rush

hours) and one swing-run driver, or \$143 per day.²²

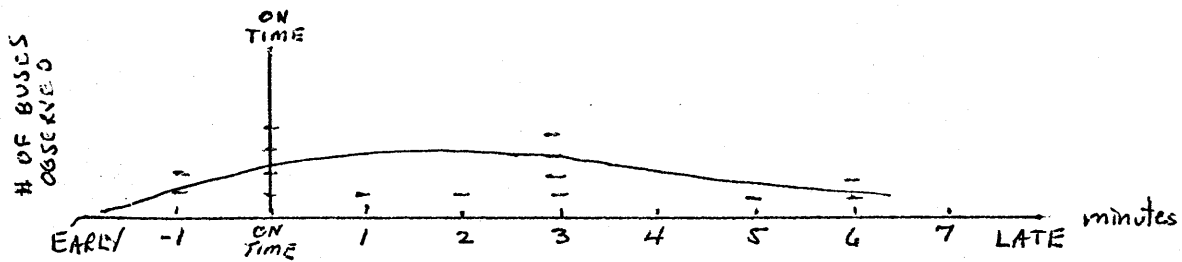
Thus it appears that the MBTA may have not only increased trip costs for some of its riders, but also may have incurred a loss itself. The need for evaluating the variation in actual headway and running time arises from existing situations where it is desirable to know in advance the probable effect on revenue of changes in the schedule which would affect the actual measures. The variation in running time determines the amount of reserve to be allowed in running time and/or terminal time to maintain the desired percentage adherence to scheduled headways, loads and running times.

Acceptable limits to the frequency of and variation of departures from scheduled running time would constitute an IDC, and can be measured by:

1. Frequency distribution of lateness at various points--i.e., number or percentage of trains on time, number of trains or buses one to three minutes late, number of vehicles four to six minutes late, etc. A similar distribution to the left (early trains or buses) would also be appropriate in applicable situations. Figure 5 is an example of such a distribution. It is based on fifteen scheduled arrivals at Flatbush and Nostrand Avenues, Brooklyn, on a major bus line operating from downtown Brooklyn for Thursday,

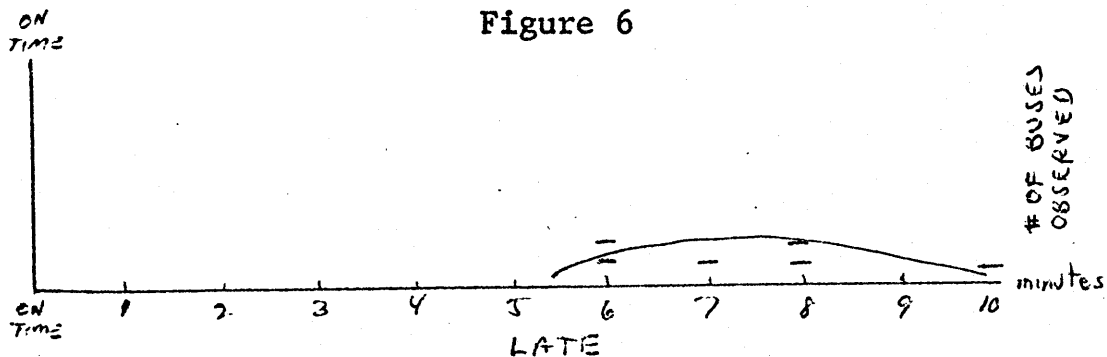
May 7, 1964, and constructed from New York City Transit Authority survey summaries.²³

Figure 5



For comparison, Figure 6 is a chart for the seven scheduled arrivals from 8:40 to 9:20 PM on the same day. Thursday is late-store-opening night in New York, and the congestion on the main shopping artery which this route serves creates a substantial deviation in actual running time. This illustrates the importance of classifying such frequency distributions by non-homogeneous days of the week and time of day. Note that at this hour, the scheduled running time is 35 minutes, as opposed to 41 minutes in Figure 5.

Figure 6



This information could also be recorded as variations in running times, rather than in arrival times. For the two examples shown above, the variation on the first would encompass 40 to 47 minutes on a 41-minute scheduled time, and on the second 41 to 45 minutes on a 35-minute scheduled time.

It is important to know when and where this variation occurs. The route being used in this example has five on-line checkpoints, as well as the two terminals. Present procedure is to compute the average running time over the period of each scheduled running time. This relays insufficient information for the method proposed. For example, on Saturday, the average for each portion is often computed over 12 hours, although actual running time may vary considerably within this period.²⁴ In the above example, the geographical as well as temporal location of the variations is relevant. Time may be lost in certain areas, and not in others.²⁵ Thus a second IDC would require the limits to the variations to apply to homogeneous time periods and route segments.

Why time is lost, or gained, in actual running time over scheduled running time, is often an important question. In the second example above, the average demand at the peak point on the line leaving downtown Brooklyn, is about 12

passengers/minute from 8:30 to 9:50 PM.²⁶ The scheduled headway increases during this time from every four to every 7-1/2 minutes, producing large fluctuations in loading (the actual headway varied from 3 to 12 minutes). On the four buses with loads of from 48 to 55 passengers, the mean running time for this stretch²⁷ was 8-1/2 minutes. On the eight buses with loads of from 76 to 92 passengers, the mean running time for the same stretch of route was 12 minutes. Since the loads varied throughout this time period, it seems likely that the actual running time could be reduced by decreasing the scheduled headway (as an alternative to increasing scheduled running time to correspond with actual observations).

Another way of structuring this information is to record the range of arrival times at selected points over the course of a week, a month, or a year, for each scheduled interval. If the normal flow of traffic allows a train or a bus to make a trip in 27 to 30 minutes, how often will it take less than 25? More than 35? More than 40? How much variation will there be from day to day? Will it take 27 to 30 minutes four out of every five days, or only two out of every five days?

Predictability of Deviations

It is important to know the extent to which variations in arrival times and running times are the result of specific causes, and the extent to which they are completely random. This will indicate whether it is possible to measure expected variation of delay, and thus incorporate it into the schedule. If, for instance, the variation is described by a Poisson distribution,²⁸ the task of measuring variation of delay is easier than if no such distribution fits.

On a rapid transit system, most of the variation in running time in non-rush hours is due to mechanical failures of various sorts; the system has sufficient capacity to handle sudden surges or ebbs of passenger flow. On the surface system, a mechanical failure on one bus will not hold up those behind it (unless high passenger/seat ratios produce crowding on the doubled interval). Delays are due more to external conditions, which are more predictable than are breakdowns.

For example, the main arterial streets and river crossings in Boston and Cambridge are often more congested on Friday afternoons than other afternoons.²⁹ The causes vary from concerts at Symphony Hall to weekend ingress and egress of college and university students, and the effects are measurable. Bus lines operating on these arteries should

maintain separate scheduled running times on Friday afternoons, to avoid excessive costs the other four days, and inadequate service on Friday. Running time data should be analyzed separately in conformance with this fact.

"One-shot" changes in running times are also often predictable. More running time should be allowed during a snowstorm, in a street under repair, on a day when there is a demonstration, etc. The precise determination of how much running time should be allowed can sometimes be based on previous experience, while other times must result from educated guesses.

The actual running time and actual headway are interlocked, as the above examples show. There is another kind of variation not discussed above, however, that is more directly a headway problem, although arising out of disturbances in running time. This is the problem of on-time departures from a terminal. On a rapid transit system, this is measured by the frequency and extent of "flex" schedules, that is, of rescheduling terminal departures on larger headways due to late arrivals. For example, if arrivals on a scheduled three-minute headway are known to be 12 minutes late starting with a 7:58 arrival, and then close in to on time with an 8:34 arrival, the flex would look like Table 5. . . .

TABLE 5

Hypothetical "Flex" Schedule

<u>Scheduled Arrival</u>	<u>Actual Arrival</u>	<u>Scheduled Leave</u>	<u>Flex Leave</u>
7:40	✓	7:48	✓
43	✓	51	7:52
46	✓	54	56
49	✓	57	8:00
52	✓	8:00	04
55	✓	03	08
58	8:10	06	12
8:01	12	09	15
04	14	12	18
07	16	15	21
10	18	18	25
13	20	to Yard	
16	22	22	27
19	24	26	30
22	26	30	33
25	28	to Yard	
28	30	34	36
31	32	38	39
34	✓	42	✓

The flex schedule creates riding conditions not provided for in the normal schedule--more crowded during the early part, less traffic towards the tail end. These conditions may prevent adherence to scheduled running time on the return trip. (In cases where there is no terminal capacity--for example, to hold a train 13 minutes in the case cited above--then trains must simply leave late.)

Where late arrivals are due to controllable conditions, such as predictable surges in loading, the correct solution may not be increases in terminal time. However, in most cases,

such as delays resulting from equipment failure, the schedule solution would be increasing terminal times--requiring one or more additional trains for peak service.³⁰ The appropriate per cent of times the operating company is willing to resort to disruptions of service to passengers and late departures is another IDC and will dictate the appropriate terminal time (subject to terminal capacity). Such a decision, however, requires additional information, including:

1. The per cent of time service must be disrupted or headways lengthened so that the passenger:

- a. Believes it happens frequently, and
 - b. believes it is the normal situation--along with the attendant loss of revenue (this can be compared to the number of advertising exposures necessary to reach X% of the market).

2. The cost of providing more reliable service by lengthening terminal times. If trains are scheduled to lay up in the yard while crews have longer terminal times, the cost may be zero. If there are no trains or crews available, however, the cost will be significant.

3. The cost of late arrivals, late departures, and flex schedules in overtime, late inspections, lack of available equipment and crews at return terminals.

On bus lines, with no communication along the route,

even if there is a dispatcher at the terminal, there is no way of knowing how late buses will arrive. The consequences are irregular departures. If there is a half hour gap arriving at a terminal due to a delay along the line, and neither running time nor terminal time compensates for this, there will be a half hour gap leaving. (This sometimes happens, for example, at Park Street, Government Center or North Station in Boston, because there is no terminal time scheduled.) "Flex" schedules are thus not possible, and sufficient time must be allowed at the terminal to leave on time the per cent of times desired, as discussed earlier.

The result of inadequate running time or terminal time, coupled with late arrivals, is described in Chapter II.³¹ It is the "bunching" or queuing of buses. The same effect can also occur due to abandoned vehicles or trains. When a scheduled interval is removed from service because of an accident, breakdown, or shortage of vehicles, the actual headway at the point of removal is twice the scheduled headway. As with late departures, this can result in further deviation from the scheduled running time and headway due to the excessive loading on the next vehicle. And, as is the case with late departures, additional vehicles, although perhaps not men, would be required.³²

Recent developments in two-way radio communication

hold promise for the reduction of variations in headways on bus lines. In New York, as a result of a successful demonstration on the Lexington Avenue subway,³³ all buses and subway cars are being equipped with two-way radios linked to a central console for each system.³⁴ In Chicago, a demonstration of an "automatic bus monitoring system" is underway.³⁵ In St. Louis, two-way radios are being installed on all the buses.³⁶ Such systems should be a future consideration in alternative solutions to the problems discussed above.

One important application of wayside communication would, for example, be the more effective use of "gap" vehicles. These are vehicles stationed along a route or at a terminal in excess of the schedule requirements, for the purpose of filling in gaps in the scheduled headway. There is usually no way at present for buses stationed as gap vehicles to know when and where perturbations are occurring over a line, or how severe these may be. With radio communication between each bus on a line and a central console, or even directly with the gap bus, the gap vehicle could be dispatched with certainty into a spreading headway gap, and saved from unnecessary trips where the deviation is not as bad as it appears at the point where the gap bus is stationed. This would sometimes prove an effective alternate to increasing

terminal times.³⁷

Accuracy of Running Time Observations

The actual running time can be observed by checkers standing in the street or on platforms, or by checkers riding the vehicles. In the discussion on this subject in Chapter II,³⁸ it was pointed out that the former method does not reveal where running time is being lost or gained through the driver's efforts at maintaining schedule ("slow" running or excessive speed), where it is being lost or gained because of traffic or passenger loading, and so on. It is not unreasonable to expect vehicle operators to cloak excessive running time by slow running when checks are being taken. However, on other days these same operators will, for the most part, run at normal street speed (or full traction power) and be ahead of time, where scheduled running time is loose.³⁹

Slow running creates an impediment to other vehicles on the street, and hence a less safe situation as automobiles and trucks attempt to pass the bus, or tailgate it. On both surface and rapid transit lines, slower operation is more costly both in manpower and mileage costs.⁴⁰ The slower the operation of a line, the smaller one might expect its passenger market to be. Slow running, which is never done uniformly

by all operators, contributes to "bunching" of buses, as discussed in Chapter II.⁴¹ Thus there are compelling reasons for obtaining an accurate measure of actual running time.

Work Program

The work program or run schedule divides the operating schedule into runs for the required number of crews (see Chapter II). While the formula given in Chapter IV is useful for preliminary estimates of entire schedule changes, there is no specific formula that can substitute for a specific analysis of the work program in evaluating incremental service changes. The determination of added or subtracted manpower costs is discussed in Chapter VI. What is of concern here is the evaluation of the work program itself, in terms of the measures of efficiency suggested in Chapter IV. These measures would constitute the IDC for Work Program.

Two of these measures--percentage of paid hours actually worked and excess of terminal time, lunch, etc. over minimum required, indicate the amount of slack available for additional service in a schedule. This slack may not be correctable through more efficient run-cutting. The cause is usually either a running time not optimal for the eight-hour work day, lunch and report allowances included; or a predetermined scheduled headway in off-peak hours not

requiring the full utilization of all the operators required in the peak periods. The optimal running times listed in Chapter VI for lowest per-mile operating cost,⁴² for example, represent the most efficient use of the operator's eight-hour day. But if a rapid transit route has a three-hour round trip time, only two daily trips can be achieved and some slack will have to exist.

The value of analyzing these measures of efficiency is that the location of such slack may suggest either a change in route, through shortlining (see discussion under Frequency) or extension, or a change in headway to achieve either lower costs or, for the same number of operators, higher revenues. The example earlier in this chapter (Table 2), arising from the application of the IDC and alternative solutions to Speed, could just as easily have arisen from a consideration of the Work Program. Under the original schedule, there was considerable slack in terminal time (which in turn was the cause of the lower average speed); the route extension required no additional men for this reason.

Where contract work rules permit--indeed, analysis of the Work Program may suggest to the management that an effort should be made to include the possibility in the regulations if it is not now there--runs on a given line with spare pieces of time left over might be used to operate other lines

or short shuttle runs. Any such improvements would involve only the mileage costs, and would thus be more likely to produce a positive marginal NOC (assuming the sensitivity of revenue to a given change is known). The men might also be used, where possible under contract, for platform or street supervision or passenger guidance, incurring no cost at all.

Similarly, such analysis would reveal where better service might be provided outside of the peak hours at only the additional mileage cost. In the case of rapid transit operation with multiple-car trains, it may suggest an alternative of operating shorter trains more often, at no additional cost at all.

As an example of the evaluation of Work Program efficiency, consider the schedule and work program shown in the Appendix in Chapter II. The total paid hours for this line on the weekday schedule in 1966 was 570.16 (for motormen, excluding board tricks).⁴³ Of this number, 13.66 hours were for overtime or spread penalty,⁴⁴ and the remainder for 69 eight-hour's-pay-guaranteed runs plus one special run paying four and a half hours. Yet the actual hours worked, including lunch time, sign-on and sign-off was only 423.9.

The thirty-seven runs with lunch hours were entitled to a minimum of 21.6 hours of lunch time.⁴⁵ They were given 44.9 hours, making the average lunch hour more than twice the

required minimum. Thus the total number of hours available for additional train operation (without considering generous time allowances for terminal movements between Dyre Avenue and East 180th Street) comes to 155.9 hours.⁴⁶

Using only part of this available slack,⁴⁷ it would be possible to schedule a shortline from 149th Street and Third Avenue to South Ferry, on a ten-minute headway making the combined express headway on Lexington Avenue in the midday 3-1/3 minutes instead of the present 5 minutes from 9:30 AM to 2:30 PM. Table 6 shows the runs used for this additional service, their present and proposed actual working hours, and the scheduled intervals assigned to each.⁴⁸

Here is a case where not only is it possible to reduce the standee loads along Lexington Avenue without running extra seats the full length of the line,⁴⁹ but to do it without any additional labor cost beyond the 27 minutes in overtime.

Another measure of efficiency is the amount of overtime reported daily beyond the scheduled overtime. An excess of non-scheduled overtime would indicate that either running time or recovery time is insufficient. It may, for example, prove necessary to have lunch hours twice the minimum required, as noted on the previous page, in order to allow sufficient recovery time from rush hour delays to avoid

Table 6

Assignment of Extra Midday Shortline Runs, Lexington Express

Run No.*	Actual Hours worked		Assigned trips (leaving 149th Street)
	<u>Now</u>	<u>Proposed</u>	
20	7:39	7:39 +	9:27
21	7:59	7:59+	9:57
30	5:44	7:15	11:57
32	4:21	6:58	9:37, 10:57
33	4:54	7:42	12:07, 1:27
34	4:23	7:03	9:47, 11:07
35	4:40	7:44	10:17, 11:37
36	4:33	7:22	12:17, 1:37
37	5:10	7:41	1:47
38	4:35	8:11	11:17
39	4:39	6:17	1:57
40	3:57	7:09	1:17, 2:35
41	5:34	7:10	12:57
42	6:09	7:50	12:27
43	4:03	6:30	10:37
44	4:49	6:40	10:47
46	4:18	7:24	1:07, 2:27
47	4:19	7:12	12:47, 2:07
48	5:22	8:07	10:27, 11:47
49	5:48	7:32	2:17
50	4:49	7:28	10:07, 11:27
62	5:38	8:09	12:37

* From IRT Division Work Program File # 3 - 1743A

+ Extra trips achieved by shortening lunch hours and eliminating deadhead layup times (trains used in extra service).

overtime payments and late departures.

Smaller changes, involving one or two trips, will often be suggested by analysis of the work program. The schedule specifications should never be considered fixed. The whole process becomes much more flexible when analysis of the work program is used as feedback into further modification of the operating schedule. For example, it may turn out, through evaluation of the work program, that a man is available to run a half hour headway for an additional hour on a low-density line that goes to hourly service at night. The essentially free labor on the extra run may make the difference between the extra mileage cost and the extra revenue (marginal NOC) small enough to warrant scheduling the trip.

Transfer Volumes

The most common Initial Directive Criterion for determining whether any change in service should be made as an outcome of analysis of this variable would be the minimum volume or percentage of transfer necessary to warrant a change. Both measures are relevant, because a high percentage of boarding passengers having transferred from another line may still be a low volume. For example, about 20% of the passengers arriving at Arborway-Forest Hills station in Boston

on the various feeder bus lines transfer to the Arborway-Huntington streetcar line,⁵⁰ and comprise over 90% of the passengers on the car line leaving the terminal. But the number of passengers per vehicle is small, and a through service would not be warranted.

Because of the diverse destinations of passengers on any given line, as is seen in the postcard surveys (which are the best source of information on the destinations of transferring passengers), small transfer volumes at any given point on a line would be more common than not, except at certain terminals, such as feeder stations. A small end-to-end transfer movement would be easier to accommodate through combining services than would an on-line volume. In the above example, a combination of the Huntington line with a principal bus feeder operating on similar headways in the rush hour and multiple headways of the car line in the non-rush hour would be feasible were it not for the technological non-compatibility of the lines.

The principal aim of analyzing transfer volumes is to determine where through service or rerouting might serve a greater number of passengers and reduce the need to transfer. Why do this at all? Many in the transit industry will argue that combining or through-routing two lines will be infeasible because traffic congestion reduces the reliability of

longer routes, and the meshing of headways will produce too much service on one or the other of the lines.⁵¹

The statistical tests of data on the effects of through service in Chapter V showed that the institution of through service produced significant increases in riding.⁵² Even where the transfer volume is small, two end-to-end lines operating on a 12 and 15-minute headway respectively would most likely attract more than enough additional riders on a combined 12-minute headway to offset the additional cost. If one line is on a 30-minute headway and the other on a 12-minute headway, a combined headway of 24 minutes with a shortline to fill in the 24-minute headway on the present 12-minute route would be a suitable solution.

The shortline vehicles would have the same load factor at the peak load point as the through vehicles if the through riding being serviced by the combination was bound for destinations prior to the peak load point, as was the case in the example cited above. This, however, is one factor that must be analyzed. It is less likely to be the case on a subway line to downtown: for example, the 145th Street-Lenox shortline on the Broadway-7th Avenue express in New York has lower load factors at the peak load point than the through service from White Plains Road, because many of the latter riders are bound for or beyond the peak load point.⁵³

It should further be noted that in avoiding the through-routing of services, a transit system will end up with many short routes, with a greater proportion of the total vehicle time being spent in terminals. The combination of two lines may often wholly eliminate two intermediate terminal times, thus compensating in part for the headway differences.

As for the reliability of the service, certainly there would be no problem in non-rush hours on most lines; keeping two lines separate while traffic is heavy may be a feasible compromise. However, the increased variation in running time, headway and load resulting from a longer line would be no different from the present variability of these factors on existing lines operating through congested areas, in rush hours and at other times as well.⁵⁴ The placement of a starter (dispatcher or street supervisor) at the original intermediate terminal points would effectively place the two line segments on the same reliability basis as they operated on when separate. The dispatcher would regulate the departure time of buses coming from either direction by holding them to their scheduled time (the buses would have a few minutes on-line recovery time). Only major traffic jams or street blockages would then adversely affect the reliability of service on the second line. The increase in riding due to the through service would probably pay for the dispatcher. If

the bus drivers were properly trained and given the incentive, they might even dispatch themselves.

This last point bears some thought. On most bus lines, there are no dispatchers at the terminals to start the buses off on time; but they leave, for the most part, on time when they know they will be penalized for early or late departures (not, of course, for late departures outside their control due to the lack of terminal recovery time for late arrivals). Most cases in New York, for example, of late departure from terminals are due to congestion at the bus garages and the late arrival, as a result, of put-ins from the garage to the terminal.⁵⁵ The drivers usually leave on time from the terminals because the importance of doing this has been stressed to them. It is probable that the management could obtain equally good results by stressing the importance of on-time departures on-line, as well as other techniques to narrow gaps in service during periods of congestion; it may not be necessary to impose the sanctions used in Cleveland, either.⁵⁶

On-line transfer volumes to crossing or connecting lines present less opportunities for through service. Where one line is at its terminal and the other gives to it large numbers of transfer passengers without replenishing its own load, through-routing of alternate buses might be feasible,

particularly if the terminal line operates on approximately half the headway of the donating line. An example of this might be the transfer from the 1st and 2nd Avenue bus lines in Manhattan to the 49th-50th Street crosstown bus line at all hours of the day. As many as one-third to one-half of the passengers coming from north of 49th Street on the 1st and 2nd Avenue line transfer to the crosstown line and vice-versa.⁵⁷ Since the peak load point on the 2nd Avenue line is at 57th Street, the buses operating south of 49th Street may well have only about half the load at the peak point; every other bus from the north might thus turn into and continue down 49th Street to the west.

Analysis of load data at other points along this line, however, indicates that the loads on the 1st and 2nd Avenues route are replenished at the peak point in the opposite direction during much of the day. Thus any vehicle diverted crosstown on 49th Street would have to be replaced on the return trip. This means that the through route would require additional vehicles operating north of 49th Street. Further analysis of the 49th-50th Street route data also shows that an almost equal volume of passengers transfer from the opposite direction lines on (for westerly movements) 1st and 3rd Avenues.

In evaluating such a case, it may also be useful to

know the destinations of the transferring passengers. The Second Avenue line does not provide free transfers to either the 57th Street or the 42nd Street crosstown lines. If such transfers were permitted, the transfer volume might spread out more evenly over the three lines and make through-routing down 49th Street less feasible. This would depend on the percentage of passengers now transferring at 49th Street who are ultimately bound for destinations in central or west midtown above 53rd Street or below 46th Street. Such information would have to be obtained from a postcard survey.

As would be the case for any of the other state variables, Transfer Volume must be evaluated by homogeneous time periods.⁵⁸ It might turn out that, for example, a much greater proportion--60% or greater--of Second Avenue line passengers transfer to the crosstown line at night, because of the concentration of entertainment activity on the west side in that area. A through service of alternate buses at night only would then be^a suitable consideration. The need for a special route to serve a school or industrial plant might be discovered in this way. Or, a heavy transfer volume might result from a special event, such as a ballgame or parade.

Unserved Origins and Destinations

There are two sets of data from which IDC's can be formed for this variable. One is information on existing routes and schedules and on existing population and activity concentrations. Without specific information on the trip patterns in terms of origin and destination link volumes, it is still possible to evaluate the "route generality" of a line.⁵⁹

Since most passengers on bus lines come from one-fourth mile or closer,⁶⁰ it is a logical corollary that only a small proportion of a population living greater distances than the quarter mile from a bus service (or one-half to two-thirds of a mile from a rapid transit line) will go anywhere by transit, particularly if they have access to automobiles. Thus one IDC may be that wherever a distance of .8, or 1.0 miles or greater exists between services, a new route should be considered. Whether such a route is implemented would depend on the population density, number of cars per household, focus or dispersal of trip destinations from the area, etc. At the same time, it may be worth considering abandoning a service which is an eighth of a mile on either side from other lines and not a strong line. Here again, the decision must rest on alternative possibilities of rescuing the service, such as extensions or route modifications, as well as the

extent to which it serves a different set of destinations from its neighboring lines.

Hours of service would be another piece of information from which IDC's could be formed. Simply, the lack of service in the evening or on Saturday or Sunday on any route serving a residential area, or activities such as entertainment or hospital facilities might call for an analysis of the effect of providing service. Frequently such service lacks on newer routes (that is, routes established since 1945) because of a reluctance on the part of management to provide service in these hours unless pushed to do so. The sight of a vehicle with only a few passengers on it at night is disturbing to most transit operators, and they wished to avoid the possibility of adding to their deficit, particularly where the new services served communities or areas of high automobile ownership.

Yet the provision of such service, particularly in a feeder operation, need not be a loss proposition. For example, in early 1965, after pressure from residents of the area, evening service on weekdays only was instituted in Boston on the Wakefield and Truman to Mattapan bus line, as an "experiment." The route is paralleled for about 45% of its service area by another line to Wolcott Square from Mattapan. On Wednesday, January 13, 1965, the Wolcott line registered 140

passengers inbound and outbound at Mattapan from 7:00 to 11:00 PM. Three months later, on Wednesday, April 28, the new service alone had added 117 riders. By June 7, 1967 (also a Wednesday), with riding on the Wolcott line up to 182 passengers (probably in part due to the combined headway providing 20-minute instead of 40-minute service along River Street), the new service was carrying 155 riders.⁶¹

Making the conservative assumption that no riders boarded at Cleary Square (although there are stores and entertainment facilities there), that the 155 riders did not represent new round trips but only new one-way trips (although 137 of them were outbound, and thus clearly had gone in prior to 7:00 PM), that the increase of 42 passengers on the Wolcott line was not due to the service change, and that the 155 new passengers were paying the average fare of 23¢ postulated earlier in this chapter (although there is reason to believe that a higher proportion of evening riding is bound for downtown Boston, hence paying the 30¢ fare; the postcard survey did not continue past 6:00 PM), the MBTA gained at the very least about \$36 from the new service, at a cost of four hours of labor and 47 miles of vehicle operation, or \$41.⁶² Because of the string of conservative assumptions above, it is probably safe to assume that NOC was actually increased.

The logic of discontinuing off-peak services is also not entirely clear when the data is analyzed. For example, in 1960, 713 passengers were counted arriving and leaving Central Square on the Oak Square (then Faneuil) line.⁶³ At 23¢, this would constitute a revenue of \$164. Actually, MBTA data show that the fare rise in 1961 brought virtually no gain in revenue on Sunday on many lines.⁶⁴ Under the 1960 fare structure, the revenue would have been 18¢ a passenger, or \$129.⁶⁵ Assuming that revenue would not have increased, the cost, \$157, would have exceeded the revenue. But again, all that would be needed to reach a break-even point would be some riders on-line, disembarking before the peak load point (indeed, a Church bus is still run in Brighton in the morning); a smaller passenger loss due to the fare increase; a higher proportion of riders transferring to the subway; or a further increase due to a combined headway with the Watertown line in Cambridge and Allston (by 1962, Watertown line patronage on Sunday had dropped from 674 to 400; it is interesting to note that although riding was initially lighter on this line, it was the other line that was eliminated).

Service linking important institutional and activity areas, based on map analysis and data on employment, visitors (to museums or hospitals), enrollment at universities or

observations of automobile congestion at such locations, would constitute another IDC. For example, there is at present no direct service from Harvard Square to the area in Boston about three miles distant containing Harvard Medical School, several major hospitals, Boston University, Simmons, Northeastern University and Boston State Teachers College, the Fine Arts and Gardner Museums, etc. A subway trip with a change through downtown at a fare of 30¢ or a bus and streetcar trip at 40¢ or 50¢ is required. The commonality of interests between the two areas, and the high density of activities in both would almost surely guarantee that even a 10¢ fare bus service would prove viable.

When such a situation is located, it is of course desirable to use other data to corroborate the finding and to estimate the demand for the service. For example, the postcard data from the Harvard to Dudley bus line show only one trip out of some 500 sampled bound for any of these areas.⁶⁶ Clearly no one uses this more expensive, although somewhat faster alternative. The home-interview survey shows an even more compelling figure. Out of over 1,000 one-way trips to three zones comprising a major part of this area (the volume is probably underestimated),⁶⁷ only 25% were made by transit. The modal split to an equi-distant area served directly by the Harvard-Dudley line was 58%.⁶⁸ These

findings seem to confirm the original analysis.

The above example illustrates a principal manner in which home-interview origin and destination survey data can be used. The IDC to be applied would be either a minimum desired modal split for a given trip purpose or trip destination (the percentage transit trips should obviously be higher for trips bound for areas with inadequate parking and highly dense activities, such as the Central Business District), depending on income and automobile ownership (again, a higher modal split would be expected for a low income area); or, rather than a minimum, a comparative analysis such as the above: if the split is 58% in one corridor, what can be done to raise it to that level in another.

As with the analysis of transfer volumes, in addition to the percentage modal split, the volume of trips involved is relevant. A low percentage using transit and a high volume would merit consideration of a new route or other major service alterations; a low percentage using transit in a movement of 100 people might be impossible to raise without incurring large costs (negative NOC), unless it took place at one specific time. Further, changing the modal split on a low volume of trips would have less of an impact on the external environment as well; that is, on highway or street congestion.

Time of day can, as pointed out above, also be important. Analysis by homogeneous time periods would be in order. Trip purpose and the nature of the destination would be equally important: shopping trips to a planned suburban shopping mall will be difficult to win over to a transit service. This is not to say, however, that such trips should not be analyzed, even if the best modal split would produce only 5% for the transit system. The important question, in the end, is not how many trips or what share of the trips are involved, but rather whether serving these trips would better meet the stipulated objectives of the management, be they maximum marginal NOC, break-even, service to all destinations attracting 5% or more of the trips from a given area, etc. In the above case, a short rerouting or extension of a line might bring a higher NOC even for only a 5% share of the trips, or a few trips an hour. No alternative should be rejected without first evaluating its consequences.

Another IDC using origin and destination data may be total volume of trips, rather than the share or modal split. That is, even where no trips are made by transit, it may be specified that any movement between zones or groups of zones greater than a given volume, and amenable to being served by bus (or rapid transit) service, would be considered to constitute a deficiency in the State variables. For example, the

Boston home interview data show 2,386 one-way trips daily from the area in west Somerville and east Medford centered around Tufts University to a large shopping complex at Wellington Circle across the Mystic River some 1.5 to 2 miles distant.⁶⁹ Only 103 of these trips are made by transit: the complex was opened gradually since the Second World War,⁷⁰ and no new services have been provided in this area in that time. In order to reach the center, it is necessary to travel all the way in to Sullivan Square rapid transit station (or out to Medford Square) and transfer to an infrequently run line (the headway is 24 minutes).⁷¹

In any case such as this, the analyst should always be aware of the fact that providing a direct service to serve this movement will also provide a link that will be used by trips to other zones made more accessible. In the above case, the population served will be able to reach most points in Medford and Malden more easily through transferring to other lines running through Wellington Circle; similarly, the population living in adjacent areas in Somerville and Cambridge can transfer to the new line to reach Wellington Circle. The total number of such subsidiary trips in this case is 2,907 one-way, of which 523 are presently being made by transit.

As suggested previously, the origin and destination

data might also be used as the basis for additional objectives on the part of management. Previously the objectives mentioned in this discussion centered around either costs (NOC) or revenues (and thus passengers), quantities directly measurable from the operation of the transit system. However, it may also be desired to specify objectives such as serving any origin-destination trip link or group of such zonal trip links above a given volume; or serving any movement to a specific destination from an origin area comprising X% or greater of all the trips from that area; or providing direct through service to the single most popular areal destination for a given population (perhaps excluding the downtown in cities with rapid transit systems).

In using home-interview origin and destination data, care must be taken, as with postcard survey data, to be informed of sources of error,⁷² and of the limitations of the survey. In Boston, for example, as in most other cities, the interviews asked for all trips made the previous day. Since interviews were generally not made on weekends, the higher volume of trips to entertainment facilities on Friday night through Sunday would not be reflected; nor would recreational trips during the summer be captured. In addition, whole new complexes of destinations have arisen since the 1963 surveys, specifically the Prudential Center,

Government Center and Charles River Park projects.

Sensitivity Analysis

In evaluating alternative changes designed to improve the State of the system, the sensitivity of the outcomes to changes in fixed elements or external influences should always be examined. The probability of a change in these variables outside the control of the transit management may sometimes prove decisive in favoring one alternative over another. While such analysis may not be as important in dealing with incremental changes in service or in bus routes, which can be changed again quickly to meet changing external conditions (as opposed to the design of a capital-intensive investment, such as the alignment of a rapid transit line), it still is of value in picturing the extent to which the success or failure of a given alternative depends on the stability of the fixed and external variables.

For example, it is clear that a growth in population would in general be more favorable than a decline in population or a stable population from the management's point of view. If two alternatives are possible, one serving an area of known population growth, another of known decline, then the probability of analysis based on present population or service areas and predicting a break-even point succeeding

would clearly be higher in the area of population growth.

This need not uniformly be true; it may be that the stipulated service has no capacity for additional riders, and that adding service to accommodate new riders as population grows will be necessary but uneconomic. Another important consideration is that the area of population decline may be a low-income area; political pressures, particularly if it is a black community, may require placing the service there, even though it may be--on the basis of the sensitivity analysis--the less economic choice from management's viewpoint. This would be a case of overriding community values, and there will be many such cases in actual practice. An axiom of this report, as should be clear by now, is that in more cases than is now generally believed, what is better for the community as a whole is often better for the operating company as well.

Summary of Initial Directive Criteria

Frequency

Optimum Headway table (subject to recalculation on examination of other State variables)

Minimum or Maximum Headway

Scheduled Connections

Speed

Minimum or maximum acceptable speed

Load

Stipulated Load factor

Direction of marginal NOC

Seats for all or Maximum load factor per vehicle

(as opposed to average)

Per Homogeneous Time Period

Duration of load

Actual Headway, Running Time and Terminal Time

-Frequency and extent of departures from scheduled

-Per Homogeneous Time Period

-Per route segment

Relation to predictable deviations in external conditions

Percent late departures and disruptions in service

Work Program

Percent paid hours actually worked

Excess lunch or terminal time

Actual overtime

Transfer Volumes

Minimum volume or percent of transferring passengers
subject to replenishment further on and destination of
transfer passengers

Unserved Origins, Destinations, Activities

Unserved population and activity concentrations
("Route Generality")

Hours of service

Unserved linkages of institutional and activity areas

Minimum or comparative modal split (subject to volume)

Large total or directional volume of trips

Footnotes

1. M.B.T.A. Timetables, Winter 1968.
2. See example in Chapter V, page 115.
3. Based on postcard survey data from 1963 (see Chapter V) which show 50% of feeder bus riders transferring to rapid transit, 30% to buses and 20% walking to their destination.
4. Since no statistical hypothesis on the effect of coordinated schedules could be developed on the strength of present data, it was assumed that demand would not be affected by the coordination. While this is an unlikely assumption, the relative effect on NOC of the alternatives tested would still be the same.
5. Chapter IV, page 124.
6. From transformation equations, see Chapter IV.
7. M.B.T.A. Timetables, Winter 1968.
8. From service area calculations, see Chapter V.
9. Assuming $2/3$ of one-way passengers in the peak eight hours evenly distributed.
10. See Chapter V, page 141 for definition of homogeneous time periods. Variation over a large time period including surges in loading caused by a ballgame, or precipitous drops in loading caused by a downpour, would, over a long enough time be random; but there is no point in scheduling the same service for such widely varying conditions (see the discussion on homogeneous time periods in Chapter V).
11. See, for example, Chemical Rubber Co., C.R.C. Standard Mathematical Tables, ed. Robert C. Weast, 13th Student ed. (Cleveland, 1964), pp. 418-421.
12. Courtesy of the M.B.T.A. Timetable Department.
13. F. W. Doolittle, Cost of Urban Transportation Service (American Electric Railway Association, 1916), p. 114-116.

14. For example, on Saturday, Nov. 27, 1965, a spot-survey of the Lexington Avenue local from 5:00 to 5:30 PM at the peak point showed loads on the four trains surveyed of between 80 and 130 passengers per car in the middle four cars of the ten car trains, and loads of from 25 to 55 in the outer four cars (each car seats 40).
15. Observations by the author show loading in Cambridge on the Harvard to Dudley line to be some three times as heavy on Friday nights as on other weekday nights (the same schedule is operated on all weekday nights); MBTA daily revenue tabulations show total Friday revenue on this line to be 10 to 15% above Monday through Thursday revenue.
16. Op. cit., note 13, p. 117.
17. Nor is this a recent phenomenon: see Bion J. Arnold, The Traffic of the Subway (N.Y. State Public Service Commission, Dec. 31, 1908).
18. For example, the peak southbound daily load on the Third-Lexington Avenues bus line in New York, at 61st Street, is 14,583. At 23rd Street it is down to 7,126, and by 4th Street merely 2,522 (based on MaBSTOA checks on March 30, 1967). Presently, of 630 vehicles passing the peak point, 257 operate all the way to City Hall (26 minutes from 23rd Street), 527 operate as far as 6th Street, and all but 41 of the remaining 103 operate to 23rd Street (although the load at 42nd Street is 12,445). Here is a case where substantially less service need be operated on the outer portion of a line than at its peak point.
19. See Chapter V, p. 178.
20. There is less traffic congestion in the morning, and thus less variation in running time; in addition, the decrease in scheduled running time effected in the Spring of 1966 by the MBTA was greater in the evening than in the morning.
21. The peak vehicle requirement in Boston is in the morning rush hour.
22. See Chapter VI for cost derivations.

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23. Courtesy of New York City Transit Authority Surface Timetable Department.
 24. The average running time, for example, from Nostrand Avenue to the next northern timepoint varies from 10.9 minutes from 9:00 to 10:00 AM (with only 11% of the vehicles exceeding the average) to 13.9 minutes from 2:00 to 3:00 PM (with 33% of the vehicles exceeding the average). The scheduled running time is 10 minutes.
 25. For example, of 41 buses leaving the north terminal from 1:00 to 4:00 PM on Saturday, the average actual running time to the first timepoint for 26 buses leaving on time was 11 minutes; for 15 buses leaving late, it was 9 minutes. Most late departures were due to the operator's preference to "kill" the extra time in the terminal stand rather than on the street (the scheduled running time is 12 minutes).
 26. Based on New York City Transit Authority survey summary data.
 27. From the north terminal to the first timepoint.
 28. See page 304.
 29. Based on recorded observations and surveys, 1963 to 1967, by the author.
 30. The cost can be substantial. For example, a "flex" schedule was operated in the morning on each of the first 14 weekdays of January, 1967 from Utica Avenue station in Brooklyn on the IRT subway division. The delay over scheduled leaving time ranged from 5 to 27 minutes. Two extra trains (minimum scheduled terminal time increased from 10 to 16 minutes) would have eliminated only three of these "flex" days; three extra trains (terminal time 19 minutes) would have enabled 8 days of schedule adherence. Four extra trains would have been required to cut the number of "flex" days to only 3 out of fourteen. It is not even clear that there is sufficient terminal capacity at Utica Avenue to handle the scheduled 22-minute terminal layover time on the three days when 5-6 minute "flex" schedules were operated.

31. Pages 40-41 .
32. Operation of a smaller vehicle than scheduled can also produce perturbations in running time and headway by carrying an actual load greater than scheduled.
33. New York City Transit Authority, Two-Way Radio Communication Mass Transportation Demonstration Project, Final Report, Project NY-MTD-8 (no date, publ. 1968). "The Authority considers the demonstration a success . . . it has committed itself to the extension of the two-way radio system to all of its rapid transit and surface divisions." (p. 3.)
34. According to The New York Times (May 15, 1968), p. 49, equipping the 4,200 buses (2,500 of which were already equipped as of the above date) will cost 7.2 million dollars; operation and maintenance will cost 1.4 million dollars a year. The system also provides a public address system inside and outside of each bus and walkie-talkies for curbside and patrol supervisors.
35. Chicago Transit Authority, Transit News (March, 1968), p. 4. In addition to two-way radio communications and an alarm system, the demonstration will provide for the electronic transmittal of locations, bus and route numbers into computer storage, subject to recall and visual display at the control center.
36. Metropolitan, 64, 1 (Jan./Feb. 1968), 21-23.
37. A gap bus stationed, for example, at Nostrand and Flatbush Avenues southbound on Saturday would have made 21 trips between 10:00 AM and 10:00 PM on the day of the survey (or two trips an hour to Avenue N and Flatbush) if continuous information was available to it on approaching headways. These trips would have closed gaps of from 8 to 18 minutes on a scheduled four-minute headway.
38. Page 37.
39. Based on thirteen years of extensive observations by the author; see also footnote 25.
40. See Chapter VI; also see discussion of Work Program, this chapter.

41. Pages 41-42.
42. Page 230.
43. IRT Division File # 3-1743A, Motormen and Conductors 1st Position Daily Work Program, Courtesy New York City Transit Authority Department of Schedules and Traffic Studies.
44. See Chapter II for definition of these terms.
45. Based on 35 minute minimum. The other runs were either trippers (less than six hours work) or swing runs, requiring no lunch hour.
46. 556.5 less 423.9 plus 44.9 less 21.6.
47. Due to the non-optimal running time and also to the extensive rush hour scheduled requirements.
48. Care was taken not to assign more than six hours per block, or less than two hours between the AM and PM blocks, on the swing runs.
49. See pages 310 . The standee loads referred to are a result of uneven distribution through the train. For example, on March 31, 1966, the load factors per hour at 14th Street and Lexington Avenue northbound in the first six cars of the ten car trains from 11:00 AM to 3:00 PM were 138%, 144%, 159%, and 160% per hour (according to New York City Transit Authority surveys). On some trains, the load factor exceeded 200% in these cars (the last four cars consistently had seats).
50. Based on analysis of the postcard survey (see Chapter V).
51. According to the late Charles L. Patterson, chairman of the New York City Transit Authority for about 12 years, in a letter to Mr. Jason Fane dated November 14, 1960, "Combining end-to-end lines, in order to create one long line, is not sound practice, since such action would result in operating more buses than necessary over the more lightly patronized portion of the route. This fact, and the inevitable reduction in revenue which would follow, would add greatly to operational costs, making such merger economically impractical."

52. 90% in the non-rush hours. See Table 6, Chapter V.
53. Based on New York City Transit Authority surveys.
54. The Harvard to Dudley line in Boston and the First and Second Avenue lines in New York are two good examples of low non-rush hour reliability indexes.
55. Or due to excessive scheduled running time. Based on examination of New York City Transit Authority surveys of the B-41 Flatbush Avenue line as well as numerous observations over the last 13 years by the author.
56. Docking a driver one full day's pay for each minute he is observed ahead of schedule. See Chapter II.
57. Based on observations by the author.
58. See Chapter V, page 190 and Table 12.
59. See footnote 103 and page 196, Chapter V.
60. See Table 8 and footnote 74, Chapter V.
61. Data courtesy of the M.B.T.A. Timetable Department.
62. See Chapter VI for cost data.
63. Based on M.B.T.A. Timetable Department survey, June 5, 1960.
64. The system as a whole gained 3 to 4-1/2%. Data from M.B.T.A. Accounting Department.
65. All passengers transferring paid 20¢; the postcard survey data show 80% transferring to either a subway or a bus line.
66. Based on hand analysis of printout of coded cards for this line.
67. Due to the coding errors discussed in footnote 3, Chapter II, and footnote 110, Chapter V.

68. Based on Traffic Research Corporation output tabulations of zonal trip interchanges by mode, zone 215 to zones 115, 116, 117 and 26, 27, 35, 114.
69. From above output. Zones 228, 229, 230 to 235, 236.
70. Based on an examination of system route maps.
71. From M.B.T.A. timetables.
72. See footnote 110, Chapter V.

CHAPTER VIII

SCHEDULE AND ROUTE PLANNING APPLIED: AN
EXAMPLE: THE B- 3 AVENUE U BUS LINE IN
BROOKLYN, NEW YORK

CHAPTER VIII

Schedule and Route Planning Applied: An Example The B-3 Avenue U Bus Line in Brooklyn, New York

Introduction

In this chapter, the method of Schedule and Route Planning developed in the first seven chapters is both reiterated and illustrated by means of an example. Using an existing bus route in Brooklyn, New York, a set of Initial Directive Criteria is postulated; the fixed elements and State of the route described (based on actual data); alternative changes chosen on the basis of matching the State variables to the Initial Directive Criteria; and the alternatives evaluated in terms of the costs and revenue estimates based on Chapters V and VI.

By referring back to the model (Chapter IV) and to the other chapters as noted throughout the text and footnotes of this chapter, it is hoped that the reader will be able to better understand how the proposed method works, and what the various steps actually accomplish.

The specific recommendations and projected costs and demands are intended to illustrate the method. The reader inclined to take exception to specific proposals or numbers should realize that the validity of these specifics is not

crucial to the validity of the method itself; indeed, one purpose of this thesis is to suggest areas that are in need of further research. What is important is not the precise quantities themselves, but the way in which they are derived and used.

The B-3 line was chosen as an example primarily for its simplicity. The weekday schedule requires seven vehicles and sixteen runs;¹ annual passenger traffic is somewhat under two million.² This makes the route and schedule easier to manipulate. A more complex and heavily used line, such as the First and Second Avenue (M-15) route in Manhattan, although presenting more dramatic problems and solutions, would require computerization of the analytic and run-cutting procedures for effective consideration of the alternatives.³ The First-Second Avenues line requires 103 vehicles and 164 runs daily,⁴ and carries over 25,000,000 revenue passengers a year² (plus a few million more riders on free transfers).

The B-3 line was also chosen because it offers a number of problems and solutions illustrative of the methods developed in this thesis. As will be seen as this chapter unfolds, the B-3 route--according to the Initial Directive Criteria to be advanced--is deficient in eight of the eleven State variables.⁵

Finally, the B-3 line experienced a service change on

October 30, 1967: rush hour service was reduced from every 7-1/2 minutes to every 10 minutes. The easily available data on the results of this change in terms of cost and revenue enabled comparison with the recommended alternatives and calculated results of the model.

History of the B-3 Line⁶

The Avenue U line from its inception operated as a bus line, with one branch to Gerritsen Beach (now the B-31 route, see map, Exhibit 1 in Appendix), and the other to Flatbush Avenue and Avenue U. Service to Bergen Beach was provided by through streetcars from northern Brooklyn in the summer from 1896 to 1919, after which time it was operated as a streetcar shuttle, from Avenue N and Utica Avenue to Bergen Beach (the termini of the two present eastern branches of the B-3 route). In 1930, streetcar operation was replaced by bus operation on this shuttle.

In 1947 the Avenue U bus to Flatbush Avenue was extended to Avenue N and Utica Avenue. By this time the Gerritsen Beach route was a separate entity. In 1957, the Bergen Beach shuttle was combined with the Avenue U route, creating the present B-3 route.

Description

The B-3 line operates from two east terminals: East 74th

Street and Bergen Avenue (Bergen Beach), and Utica Avenue and Avenue N. Service on the Bergen Beach branch is provided on weekdays from 6:50 AM to 7:20 PM, every 30 minutes, and on weekend mornings and afternoons. Service on the Avenue N branch is provided 24 hours, with a maximum headway of 30 minutes. The western terminal is at 25th Avenue and 86th Street (see map and schedule, Exhibits 1 and 2, Appendix). The B-3 route operates out of Flatbush depot, sited on the Avenue N branch.

As shown on the map, selected free transfer privileges are provided. As is the case with other routes, the transfers reflect the franchise agreements within and between what used to be several private companies. Thus the B-3 buses bound westward issue transfers to B-41 north, B-31 south, B-44 Nostrand Avenue north, B-49 Ocean Avenue south only, B-68 south only, and B-4 south only. Transfers are not issued to B-36 service south towards Sheepshead Bay, B-44 service south towards Emmons Avenue, B-2 service north towards Kings Highway, or to any northward service west of Nostrand Avenue, or to any lines terminating at the western terminal except the B-4 south, or to any subway lines. In an eastward direction there is no transfer to the B-41.

Mileage, running time, and other summary data is included in Exhibit 2 (Appendix).

The eastern end of the B-3 route operates in an area of population and activity growth (see description of Fixed Elements further on). It competes in this eastern area with five other routes: the B-41 Flatbush Avenue route, which by virtue of its frequent service receives the bulk of the passengers (see description of Demand further on); the B-78 Mill Basin route, started about six or seven years ago (1961-62) as a result of pressure from local community groups, and not operating at night or on weekends; a route operated by Pioneer Bus Company from Mill Basin to Kings Highway (the only franchised, regular service route in Brooklyn not operated by the Transit Authority, started about ten years ago after the Authority refused to provide service); the B-46 Utica Avenue route, which terminates end-to-end with the Avenue N branch of the B-3 line; and the B-2 Avenue R route to Kings Highway from Flatbush Avenue and Avenue U. In addition to these five routes, a sixth route passes through this area, along Flatbush Avenue bound to and from Floyd Bennet Naval Air Field and the Rockaways peninsula of Queens. This route, operated by Green Bus Lines, does not pick up passengers in Brooklyn northbound or let passengers off in Brooklyn southbound, once it is north of Avenue U and Flatbush Avenue.

The B-3 route thus serves a crosstown function as well

as a residential feeder function, by being the only funnel for passengers from all these lines bound for the Gravesend, Sheepshead Bay and Coney Island areas of Brooklyn. Similarly on the western end, the B-3 route connects at its terminus with B-4 and B-34 buses and the West End subway line to Bensonhurst, Bay Ridge and Borough Park. The western portion of the line is bisected by three other subway lines, at West 8th Street, McDonald Avenue, and East 16th Street, and thus does not serve as a feeder (there are no subway lines within several miles of the eastern portion).

The B-31 Gerritsen Beach route overlaps the B-3 route from Gerritsen Avenue to the subway at East 16th Street. Because it terminates at the subway station and provides more frequent service, the B-31 route carries the bulk of the passengers bound from the area of overlap to the subway.

The population and land use is further described under "Fixed Elements."

Initial Directive Criteria

For the purposes of the example, Initial Directive Criteria for each State variable will be postulated. Where the Transit Authority has defined criteria for a given variable, these will be used. Otherwise, the criteria set forth will be arbitrarily chosen, with possible reasons for such a

choice noted.

The general objective of the transit company will be assumed to be profit maximization, subject to the set of constraints contained in the criteria set forth below. Thus any change would be called for that would produce a positive marginal Net Operating Contribution⁷ or that would correct a deviation from the criteria listed below.

Frequency

Scheduled Headway should be at optimal Net Operating Contribution (NOC).⁷ From 5:30 AM to Midnight (the latter time referring to the peak direction of travel) neither the mainline headway or the headway on any branch should be greater than 20 minutes (assume that the Authority has found that a greater headway is never economical for them and that for the passenger it would be more economic to increase service on a nearby or parallel route, or provide taxi service); from 1:30 to 5:00 AM, no greater than every 60 minutes (a public service constraint).

Scheduled "skipped" connections between the bus and subway in non-rush hours at the East 16th Street station are forbidden. Scheduled connections where possible should be made to the B-4 and B-34 lines at the western end and to the subway at East 16th Street.

Speed

The scheduled speed should be as good or better than the Brooklyn average, and the same or faster than that of route B-31 (arbitrary).

Load (Comfort)

The scheduled average Load per half hour should be 150% in the peak hours (7:00 to 9:30 AM, 4:30 to 6:30 PM). This is--in theory--current practice. However, the maximum peak hour headway at the peak point should be ten minutes, as long as a seated load is obtained. (Assume that 150% has been found to be "practical capacity"⁸ under regular service).

The scheduled average Load per half hour (per bus on infrequently run lines where sudden surges occur regularly) in non-rush hours should be a seated load: 100% (in theory the current maximum is 115%). This would apply to special load conditions outside of the peak hours, such as late shopping nights. (Assume that it has been found not profitable to have standees in non-rush hours).

The maximum loads stipulated above should occur over no more than 25% of the one-way length in running time of the line in the rush hour. Conversely, a load factor of at least 100% should occur over the whole line in the peak hours, except for the very ends. Load factors at points other

than the peak point should be at least 65% of those at the peak.

Reliability

The next three variables describe reliability. In general, the reader should assume that it has been determined that exceeding the constraints outlined below and on the previous page produces sufficiently poor reliability to be unprofitable.

Actual Load

In the rush hours, no more than 10% of the vehicles should have loads over 175% (75 passengers per bus), per half hour; in the non-rush hour, no more than 10% of the buses should have loads over 130% (55 per bus): (Assume that research has also shown undesirable accident rates at loads above 175%.)

Actual Headway

On a line with a headway greater than 5 minutes, a double headway (16 minutes, for example, on an 8-minute headway) should never occur. In addition, no actual headway greater than 1.33 times the scheduled headway should be permitted on lines with greater than ten minute headways. In non-rush hours, any given headway should be no more than

three minutes plus or minus the scheduled headway. These two limits (plus or minus 3 and 1.33) must occur no more than 5% of the time.

Actual Running Time and Terminal Time

The Mean observed running time must not be greater than the Scheduled running time (it can be less if necessary to satisfy the further constraints listed).

Seventy per cent of all vehicles in a homogeneous time period⁹ must have actual running time less than or equal to the scheduled running time.

At least 50% must have running time equal to or greater than the scheduled running time.

Terminal time must insure 99% on time departures per homogeneous time period, with the exception of unusual circumstances (such as a fire blocking a street, street collapse, blackout, etc.).

Work Program

The percentage of actual paid hours worked should be at least 90%; lunch and terminal time excess should be no more than 20%. If either condition is violated, the runs should be examined for the effects and costs of changes in service which would bring the percentages up to par.

Any long swings or pieces should be similarly evaluated

to determine the revenue and cost effects of breaking the swing or extending the piece run(s) to make straight runs.

Overtime and late reports of any kind would require reference to actual running time and terminal time data.

Mileage

Daily revenue per mile should at least equal the variable cost of operating a route.

Demand

The calculated Demand should not differ by more than 25% from the actual demand. If it does, a reason should be sought; is there a capacity restraint; competing services; poor linkages?

Demand should increase with population increases.

Recent changes in demand should be analyzed, and the effects of recent changes in service on demand determined.

Transfer Volumes

For intersecting right angle movements, 40% or more of a turnover on both lines should be considered for a through service, when the loads on both lines are not replenished.

For end-to-end transfer movements, 40% or more of a transfer to one line (where several lines terminate in the same place) would require joining the two routes or re-arranging at least one route for through service to a portion

of the other route. Where only one other line terminates, 20% or more of the passengers transferring to that line would call for considering through service as an alternative.

Unserved Trips and Activities

A minimum daily volume of 500 one-way trips (250,000 a year) new to transit as a travel mode is required for a new direct service.

Any origin-destination volume not served directly by a through transit service but being equal to or greater than any existing volume served directly (subject to the 500 trips daily minimum), where the modal split for the presently served direct service is more favorable than for the non-direct service, calls for a new route, or modification of an existing route.

The mode split should be at least 25% to transit for transfer trips, 50% for direct trips, 90% for Manhattan.

The next service should be no further than .6 miles from the existing service; all residents should be able to reach at least one route within .3 mile walk 24 hours a day, 7 days a week so long as the service area of the route so defined (.3 miles to each side) is at least 1,500 people per mile of route. All major institutional complexes such as

colleges, hospitals, etc. should receive service to the door 24 hours a day on at least one route. Major community activities (schools, shopping, hospitals) should be served direct from within the community or by convenient transfer.

B-3 Avenue U Route Fixed Elements

1. Movement data:¹⁰

	<u>Eastern Section</u> ¹¹	<u>Western Section</u> ¹¹
Total Daily Trips 66,876	42,754	
To CBD (Manhattan)	8,182	9,223
To Downtown Brooklyn ¹²	2,393	1,848
To same zone	19,741	4,602
To adjacent zones	14,044	12,629
To Borough Park, ¹³ Flatbush, Crown Heights and Brownsville	8,138	6,406
To remainder of Brooklyn	8,670	5,680
All others	4,934	3,027

2. Population data¹⁴ (updated to 1968):¹⁵

Eastern section¹⁶ population 8,800; median annual family income \$7,210; percent households with one or more automobile, 80%.

Western section¹⁷ population 15,730; median annual

family income \$6,116; percent households owning one or more automobiles, 62%.

Gerritsen Beach¹⁸ population 7,600; median annual family income \$6,858; percent households with one or more automobile, 68%.

3. Geographic and physical structure: See map for principal geographic features, rapid transit stations, etc. (map is Exhibit 1, Appendix).

4. Land use and activities:

Major retail strips (small stores) are located on Avenue U from East 18th Street to Coney Island Avenue (including two motion picture theatres) and from McDonald Avenue to West 9th Street. Retail and restaurant junctions also exist at Flatbush Avenue and Avenue U and at Gerritsen Avenue.

A series of six-story apartment house developments exists south of Avenue U between Nostrand and Knapp Avenues, as well as south of the western terminal of the B-3 line (where the apartment structures are higher); the remainder of the line passes through residential areas consisting mostly of two-family, semi-detached or row housing, with some scattered single family housing.

Several public schools are situated on the line. A new junior high school has been built near the eastern end of the line. No high schools or colleges exist along the line, but

three high schools are sited several blocks north or south of the line. A major municipal hospital is situated five blocks south on Ocean Parkway.

5. Population growth and future land use:

Population on the eastern end of this line has been growing. From 1960 to 1970 the population increased 66% in this area.¹⁹ Construction is continuing, mostly of semi-attached or row two-family housing (50 to 100 people per gross acre). Some vacant land still exists in Bergen Beach, with large tracts just north of the B-3 line. Development is proceeding south from Paedergat Basin.

A major retail shopping center is under construction just east of the junction of Flatbush Avenue and Avenue U. Rising south of Avenue U between 52nd and 55th Streets, it is known as "King's Plaza," and will include two major branch department stores: Alexander's and Macy's. In addition, 400,000 square feet of rental space is to be available.²⁰

Marine Park, adjacent to and south and west of this same junction, is undergoing continuing upgrading as a major recreational area.

Finally, the current \$2.5 billion dollar transportation development program for the metropolitan area calls for extension within ten years of a subway line to Flatbush Avenue and Avenue U.

The Existing State of Route B-3

Frequency

The Scheduled Headway is not at optimal NOC during the peak hours; it is during the day (see Tables 3 and 4).

The Avenue N and Bergen Beach branches have a 30-minute base headway. According to the criteria, they must be either 20 minutes each for a mainline headway of 10 minutes, or one branch must be eliminated.

Connections are not scheduled in non-rush hours, and even in "hawk" hours, as stipulated; there are cases of scheduled "skipped" connections.

Speed

The scheduled speed meets the stipulated criteria. It is 9.9 miles per hour average (based on actual running time), or 9.0 miles per hour including the terminal time. The average for Brooklyn is 7.18 miles per hour.²¹

Load²²

The scheduled load in the AM peak period varies from 33% to 195%. For at least a half hour it is 195% average, and this clearly violates the 150% standard. From 9:00 to 9:30 AM it is only 33%. In the afternoon from 3:00 to 3:30 PM it is 130% to 155%, violating the 100% standard at this hour.

Occasional school crowds also create loads above the stipulated amount. For the remainder of the day loads are below the standard on 15 to 20-minute headways.

Actual Load

From 2:00 to 4:00 PM there is a considerable variation in the actual loading (see Figure 1). Other isolated deviations (as opposed to inadequate scheduled headway) include 5:00 to 5:30 PM eastbound, two (out of three) vehicles with 152 passengers, or 177% each (the third had 28 riders or about 64%); and 11:30 to 12:00 Noon eastbound, one bus with two passengers and one with 65 passengers.

Actual Headway

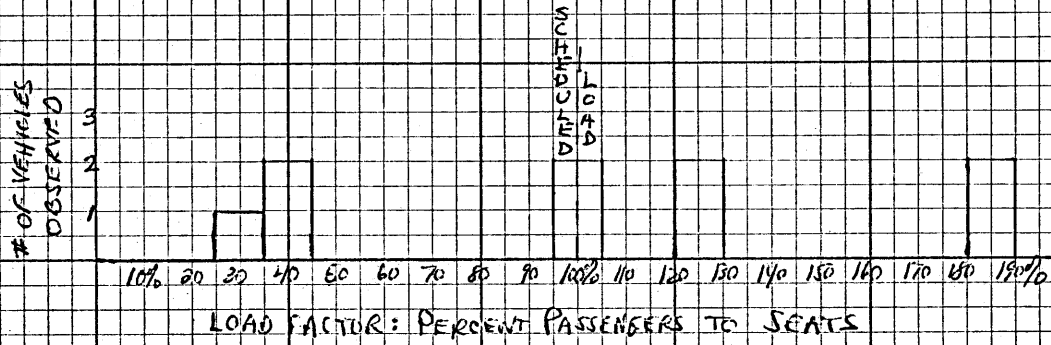
In general, actual headways on the scheduled base headway of 15 minutes vary from 12 to 17 minutes, within the acceptable limits. However, a number of isolated deviations above or below the limits stipulated earlier in this chapter occurred through the day. These included:

Double headways eastbound (two-bus bunch) due to late terminal departures (see discussion on Actual Running Time following this section) from 8:30 to 9:00 AM and 9:00 to 9:30 AM; from 6:30 to 7:00 PM westbound.

Sixteen and four-minute headways eastbound from 6:30 to 7:00 PM on scheduled ten minutes; eighteen and two-minute

FIGURE 1

ACTUAL LOAD VS. SCHEDULED LOAD
 MAY 6, 1968, MON., B-3 AVE. U LINE
 2:00 TO 4:00 P.M. EASTBOUND AT
 GERRITSEN AVE.



headways eastbound from 7:00 to 7:30 PM on scheduled ten minutes; 25 and 5-minutes eastbound from 8:00 to 8:30 PM on scheduled 15 minutes (due to early departure), and 32 and 8 minutes on scheduled 20-minute headway from 8:30 to 9:00 PM eastbound.

The 4:40 PM trip from 25th Avenue and 86th Street to Bergen Beach was abandoned for unknown cause on the day of the survey, resulting in a 70-minute actual headway on a scheduled headway of 30 minutes to Bergen Beach eastbound between 4:20 and 5:30 eastbound at East 16th Street.

Observations also indicate some trips leaving terminals several minutes ahead of schedule,²³ probably because of the tight running time (see next page).

Actual Running Time

Figure 2 shows the actual running time compared to the scheduled running time by homogeneous time period, for the Avenue N branch. The situation is similar for the Avenue U branch to Bergen Beach. Note that this should properly be done for each timepoint along the line; limitations on the reader's patience and the author's resources dictated the choice of only one set of timepoints, hence the terminal points were chosen for easier understanding of the changes to be recommended.

FIGURE 2

ACTUAL RUNNING TIME VS. SCHEDULED RUNNING TIME
 MAY 6, 1968, MON, 2-3 AVE. U. LINE, AVE. N. BRANCH

AVENUE N and UTICA AVE.
 TO 25th AVE and 86th ST.

ACTUAL RUNNING TIME
 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

6:30
TO
8:00
AM
MEAN
24 1/2

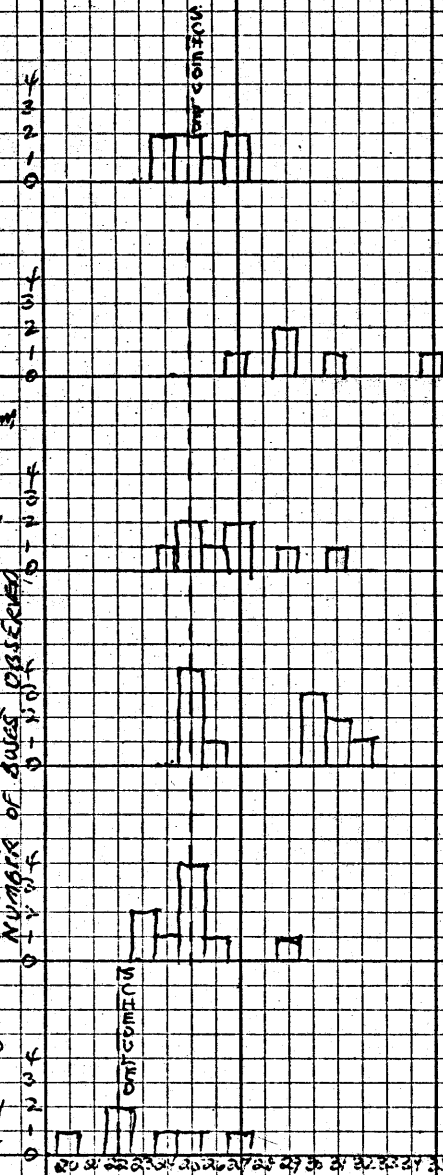
8:00
TO
9:00
AM
MEAN
30

9:00 AM
TO
1:00
PM
MEAN
27

1:00
TO
6:00
PM
MEAN
28

6:00
TO
8:00
PM
MEAN
25

8:00
TO
10:00
PM
MEAN
23 1/2



25th AVE. and 86th ST. TO
 AVENUE N and UTICA AVE.

ACTUAL RUNNING TIME
 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34

6:30
TO
7:30
AM
MEAN
24

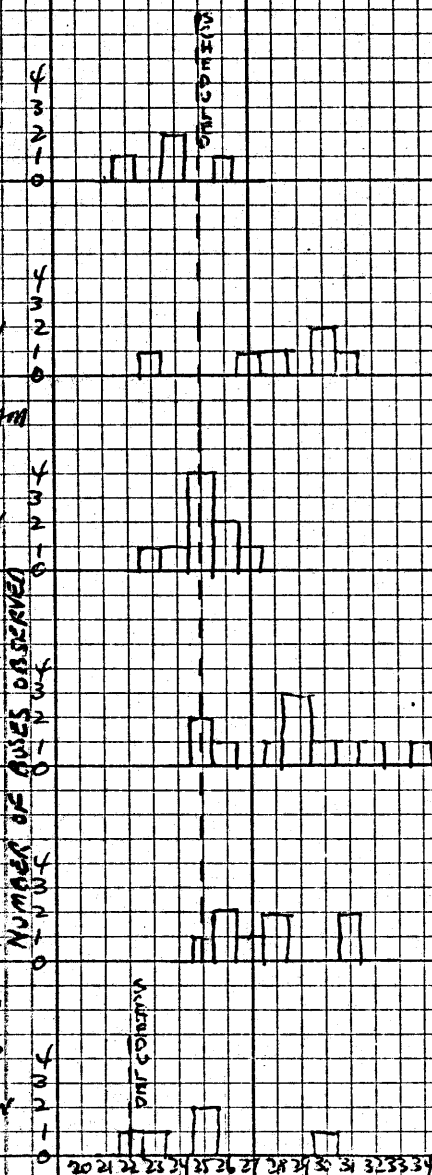
7:30
TO
9:00
AM
MEAN
28

9:00 AM
TO
1:00
PM
MEAN
25

1:00
TO
6:00
PM
MEAN
29

6:00
TO
8:00
PM
MEAN
27 1/2

8:00
TO
10:00
PM
MEAN
25



An analysis of late departures shows that at the east end of the route, all (four) buses leaving Bergen Beach between 8:00-9:00 AM and 5:00-6:00 PM left late. At the western end, from 7:30 to 10:00 AM, four out of fifteen or 27% left late; from 5:30 to 7:00 PM, four out of nine, or 44%, left late. This reflects the large deviation from scheduled running time at these hours (see Figure 2). In addition, the 1:10 and 3:40 PM trips from 25th Avenue and 86th Street to Bergen Beach left late, and the 4:40 trip was abandoned.

Work Program²⁴

The percentage of actual paid hours to hours worked is 83-1/2%, or slightly below the stipulated minimum of 90%. The minimum required lunch time (equivalent here to swing time, as the swings are all under an hour) should be 35 minutes times 15 regular runs or 525 minutes. The actual is 677 minutes, or 30% excess. Note that this excess is of no import, however, since the paid time does not include this swing time. There are no swing runs (spread over ten hours), and one piece run.

Mileage

The present revenue per mile (in May, 1968)²⁶ is 99¢. The present variable cost²⁵ is 96.67¢/mile (of which 73.5¢ is

for manpower and depreciation). Thus this criterion is met, although just barely.

Demand

Calculated demand deviates markedly in certain cases from actual demand. Table 1 lists the comparisons. Note that the match between calculated and actual demand on the control route, B-31, is quite close for both periods. This control route has no competing routes in its service area, which makes it easier to make such comparisons. Note that when passengers on the B-41 route at its terminus, which intersects the B-3 route, are added to passengers out of Bergen Beach on the B-3 route, a much closer correspondence to calculated demand is obtained.

The implication of this combined result is that, while the B-41 route on a 3-minute or better headway now accounts for 218 of the 290 passengers--although the B-3 route on a 30-minute headway is less of a walk for two-thirds of the service area--the potential for the B-3 route on a more frequent headway is considerable.

The low response on the Flatbush Avenue to Gerritsen Avenue portion in the rush hours is probably due to the capacity restraint, as well as to the B-2 route one-fourth mile away which operates to an express station. Conversely, in the

Table 1

Calculated vs. Actual Demand
B-3 and Adjacent Routes

<u>Time period</u>	<u>Route Section</u>	<u>Service area</u> ²⁹	<u>Calculated</u> ²⁷ <u># Riders</u>	<u>Actual</u> ²⁸ <u># Riders</u>
4:00-6:00 PM	Bergen Beach Branch to Flatbush Ave.	6500	0*	240
	Flatbush Ave. to Gerritsen	2320	168	70
	B-3 + B-41 at Bergen Beach	3570	263	290
	Control route B-31 (Gerrit- sen Beach)	7600	885	986
10:00 AM to 2:00 PM	Bergen Beach Branch to Flatbush Ave.	6500	101	77
	Flatbush Ave. to Gerritsen	2320	111	149
	Control Route B-31	7600	442	417

*The Bergen Beach Branch operates on a 30 minute headway. The equations used ²⁷ were calibrated for a maximum headway of 17 1/2 minutes. At 30 minutes, these equations show 0 riders.

The Avenue N Branch has no easily defined service area; it serves an area bisected by other routes, which are more direct. At least part of its patronage is transfer riders from these routes.

midday, the higher actual demand is due to a school crowd of about 50 people between 12:00 and 12:30 PM.

Patronage of the B-3 route has not increased with the population growth on its eastern end (see description of Fixed Elements). Riding has been stable for eight years, and has shown a downward trend for the last two years due to the fare increase and the change in service.

Effect on Demand of Service Change

Exhibit 4 (Appendix) shows the details of the changes in demand and costs associated with reducing rush hour service in October of 1967 from a 7-1/2 to a 10-minute headway. Both revenue audits and headcounts show a 3.4% decline in passengers from May of 1967 to May of 1968; in the same period the control line showed a growth of 3%.

Depending on whether the Authority's figure for loss of passengers (-3.4%) or loss of revenue (-4.6%) is used (see Exhibit 4), the marginal Net Operating Contribution of the change was -\$4.15 to -\$15.65 a day. That is, the loss in passengers was slightly greater than the savings in cost. This compares with a calculated marginal NOC of -\$3.00 to -\$15.00.

Note also that the effect of reducing service at East 16th Street westbound in the morning, which was operating at

practical capacity, is also as predicted: the average load per bus remained the same.

Transfer Volume

The only major transfer volume appears to be at Avenue N and Utica Avenue, between the B-46 and B-3 lines. However, no data is really available on transfer volumes.

Unserved Trips and Activities

Table 2 shows the number of trips and modal split of all zone to zone movements served by the B-3 route, as well as a set of movements served by the B-41 route and another set by the confluence of bus and subway routes in zone 312, for purposes of comparison. The zone numbers are shown on the map (Appendix, Exhibit 1). Note that other zonal linkages from zones 293 and 301 exist which are not served by and do not potentially involve the B-3 route.

Note the excellent modal splits on the B-41 route and in zone 312. The wide range in the two transfer linkages shown for route B-41 is probably due to the fact that the B-2 route, which serves part of zone 293, goes directly to the main shopping and entertainment area of zone 295 (and the B-41 line offers free transfers to the B-5 route which slices through the middle of zone 295); while the B-41 route offers no transfers to either of the lines serving zone 292, the

Table 2

Zone-to-Zone Trips and Modal Split³⁰B-3 Avenue U Line 1963

<u>Zone Pair</u>	<u>No. of Trips</u>	<u>No. By Transit</u>	<u>Percent By Transit</u>
<u>Movements Served Directly</u>			
293-293	19,741	4437*	22 1/2
293-301	1,095	436	40
293-312	871	215	23
301-301	4,602	454	10
301-312	812	267	33
<u>Movements Served By Transfer</u>			
293-CBD	7,408	5,901	80
293-Downtown Brooklyn	2,393	1,845	77
303-312	419	105	25
293-302 & 311	1,784	421	23 1/2
293-303	3,801	960	25
293-304	644	213	33
293-313 & 321	750	100	13
293-322 & 323	663	0	0
301-313 & 321	2,451	1,129	46
301-322 & 323	646	218	33
301-295	1,679	574	34
301-296	444	336	75
301-303	2,077	817	39
<u>Unserved Volumes Greater Than 500 With Poor Modal Split</u>			
301-304	2,699	549	20
301-311	978	210	21 1/2
293-272	2,794	217	8
<u>Movements Served by B-41 Directly</u>			
293-296	3,183	1,650	52
293-271	1,649	735	45
<u>Movements Served by B-41 Through Transfer</u>			
293-295	2,392	1,533	64
293-292	760	111	14 1/2
<u>Movements within and adjacent to Zone 312</u>			
312-312	5,933	2,833	47 1/2
312-313	3,917	1,926	49
312-321	4,013	2,452	61

* Approximately 50% school bus trips

B-8 and B-23 routes.

Zone 312, as can be seen on the map, has half a dozen bus lines, three of which make 90 degree turns through the zone, plus two subway lines, for an extremely dense transit coverage. A 50% modal split for intra-zonal movements is rare; the usual figure is 10 to 20%.

Analysis of Table 2 is the subject of the choice of alternatives through the matching of Initial Directive Criterial with State variables, and is thus covered in the next phase of this example. The reader can compare the criteria listed for this variable to the percentages in the table as preparation for this analysis.

Choice of Alternatives: Application of Control Variables
to Produce New State, Based on Deficiencies
Revealed by Initial Directive
Criteria Applied
to Existing State

Frequency

Tables 3 and 4 show the effects of alternative headways (for the derivation of these tables see Chapter IV, part II) on the B-3 Avenue U line for two time periods. The optimum headway is defined as the one at which NOC is greatest, subject to other constraints. Note that although the optimum is at 7 minutes, the criteria with respect to load factors calls for a 6-minute headway (this is explored further under

Table 3

Net Operating Contribution For Alternative Headways
4:00-6:00 PM B-3 Ave. U (Revised Route, no Ave. N Branch).

Actual Head- way	# Vehicles	# Trips	x11.24 Mileage	Veh. ^(a) x23 1/4	Mileage ^(b) x.2317	Cost	Pass ^(c) 1000	Svc. ^(d) Area x24.5	Rev. x.20	NOC	Avg. ^(g) Load
20	4	6	67.5	93	15 1/2	108 1/2	30 ^(f)	735	147	38	61
16	5	7 1/2	84.5	116	19 1/2	135 1/2	32	785	157	22	52
15	5	8	90	116	21	137	39	955	191	54	60
13	6	9	100.5	139 1/2	23 1/2	163	52	1270	254	91	71
12	7	10	112.5	163	26	189	59	1442	288	99	72
11	7	11	123.5	163	28 1/2	191 1/2	66	1615	323	131	73
10	8	12	135	186	31	217	73	1785	357	140	74
9	9	13	146	209	34	243	80	1958	392	151	75
8	10	15	168.5	232 1/2	39	271 1/2	87	2125	425	153	71
7 1/2	11	16	180	256	41 1/2	297 1/2	90	2205	441	143	69
7	11	17	191	256	44 1/2	300 1/2	93	2280	456	(155)	67
6 1/2	12	18	202.5	279	47	326	97	2370	474	148	66
6	13	20	225	302	52	354	100	2450	490	(136)	61
5 1/2	14	22	247.5	325 1/2	57 1/2	383	104	2548	510	127	
5	16	24	270	372	62 1/2	434 1/2	107	2630	526	91	
n/5 SL	13	12ea.	222	302	51 1/2	353 1/2	90	2205	441	87	
n/4 1/2 SL	14	13ea.	240	325 1/2	55 1/2	381	96	2346	469	88	
n/4 SL	15	15ea.	277	349	64	413	101	2475	495	82	

Table 4

Net Operating Contribution For Alternative Headways
10:00 AM-2:00 PM B-3 Ave. U (Revised Route, no Ave. N Branch)

Actual Head- way	# Vehicles	# Trips	x11.24 Mileage	Veh. ^(a) x18.4	Mileage ^(b) x.2317	Cost	Pass ^(c) 1000	Svc. ^(d) Area x24.5	Rev. x.20	NOC
20 ^(e)	4	12	135	73.5	31	104.5	37 1/2	920	184	79.5
19	4	13	146	73.5	34	107.5	39 1/2	967	193.5	86
18	5	13	146	92	34	126	42	1028	205.5	79.5
17	5	14	157.5	92	36.5	128.5	44	1078	215.5	87
16	5	15	168.5	92	39	131	46	1128	225.5	94.5
15	5	16	180	92	41.5	133.5	48 1/2	1190	238	(104.5)
14	6	17	191	110.5	44.5	155	50 1/2	1238	247.5	92.5
13	6	19	213.5	110.5	49.5	160	52 1/2	1286	257	97
12	7	20	225	129	52	181	55	1349	270	89
11	7	22	247.5	129	57.5	186.5	57	1396	279	92.5
10	8	24	270	147.5	62.5	210	59	1447	289.5	79.5
9	9	27	304	166	70.5	236.5	61	1495	299	62.5
8	10	30	338	184	78.5	262.5	63 1/2	1555	311	48.5
7 1/2	11	32	361	202.5	83.5	286	64 1/2	1581	316	30
7	11	34	383.5	202.5	89	291.5	65 1/2	1607	321.5	30
6 1/2	12	37	417	221	96.5	317.5	67	1641	328	10.5
6	13	40	450	239.5	104	343.5	68	1670	334	-9.5

Notes, Table 3

- (a) 3-1/2 hrs. x \$4.60 (see Exh. 3) manpower + 1/2 of days depreciation charge of 14.30 per vehicle (see Exh. 3), or \$23.25. 3-1/2 hrs. is minimum pay for a piece run.
- (b) Mileage Cost see Summary chapter 6.
- (c) See Chapter 5 p. ____: Pass/1000 served 4PM-6PM outbound = 141-6.8 (Headway)
- (d) Service area as defined earlier (Table 1).
- (e) Here are considered alternate vehicles terminating at Coney Island Avenue or E. 16th St. from Island E. 71
SL Mileage Coney Island Ave. - Isl. & E. 71 7.25 round trip
- (f) Formula calibrated on maximum Headway 17-1/2 min. shows 0 pass. @ 30 headway. Minimum of 30 Pass/1000 assumed consistent with existing B-3 and observations used in calibrating equation.
- (g) Assuming 1/2 of passengers each direction.

Notes, Table 4

- (a) 4 hours x \$4.60 (see _____) manpower, or \$ 8.40
- (b) Mileage cost see p. _____ Chapter 6.
- (c) See Chapter 5 p. _____ : Pass/1000 served 10:AM-2: PM inbound = 81-2.18(Headway)
- (d) Service areas as defined earlier
- (e) Maximum allowable according to Initial Directive Criterion.

the section on Value Functions).

The optimal headway turns out to be 6 (or 7) minutes in the rush hour and 15 minutes during the day.

This solves the frequency deficiency on the Bergen Beach branch in the rush hour, but would only solve it in midday if the Avenue N branch was eliminated in non-rush hours. This is discussed in the analysis of Unserved Trips. If the Avenue N branch was kept, a 20-minute headway on each branch would be required by the criteria put forward earlier, resulting in a non-optimal ten-minute headway on the mainline during the day.

The new schedule (Exhibit 5) based on the optimum headways and incorporating other changes designed to correct the Existing State also contains adjustments to obtain scheduled connections where possible and to avoid "skipped" connections. For example, the originally scheduled 5:10 AM from Bergen Beach was moved up to 5:07 AM for a connection to the subway at East 16th Street.

Load

The scheduled load is a function of the scheduled headway (as defined in Chapter IV). Since the optimal rush hour headway is six minutes, a load of 61 per bus or 140% is obtained. The schedule (Exhibit 5) goes to 15 minutes a half

hour earlier to raise the 33% load factor from 9:00 to 9:30.

The high load factor from 3:00 to 3:30 is eliminated because of the start of 10-minute headways at about 12:30 PM (required to satisfy the actual load criteria, discussed below).

Actual Load

The deficiencies noted in this State variable will be solved by changes in the scheduled load (see above), in the scheduled headway in the afternoon (by reducing the maximum load, if not the variation), and in the actual headway (see below).

Actual Headway

Of the possible control variables revealed in the Transformation functions (see Chapter IV), a change in the scheduled headway would not solve the problems in this case; nor is the load the main factor here. The other two variables, Running Time and Control, are the relevant variables.

Increased Running Time to satisfy the Actual Running Time criteria (see below) will eliminate the late departures which caused some of the deviations (see the discussion of this earlier in this chapter). Supervision will be necessary at East 16th Street to space departures from 2:00 to 10:00 PM in both directions. The one other factor contributing to the deviation of the actual headway, the abandoned trip, would be

materially lessened in effect by the new scheduled headway to Bergen Beach. An abandoned trip under the new schedule would result in a 24-minute headway (as opposed to 70 minutes).

Actual Running Time

A new set of running times is scheduled to correspond with the mean times shown in Figure 2 (a change in terminal time would not help the Actual Headway or Load and would be unrealistic). The supervision scheduled for East 16th Street will also be of help in regulating the running time.

Work Program

See the new work program, Exhibit 6.

Demand

Calculated demand should come closer to actual demand with the increases in service to Bergen Beach. Reserve capacity in the rush hour and better service all day to this area should encourage a reflection of population growth in patronage on the line. The optimum headways (see NOC Tables 3 and 4) correct the adverse affect of the recent service change.

Note that a diversion of some riders from the B-41 route to the B-3 route in the Bergen Beach area would be

expected, and may call for slight reductions in service on the B-41 route.

Unserved Trips

Analysis of Table 2

Intra-zone trips, zone 293: There are no transfers from route B-3 to any north-south routes in this zone. The B-3 and B-78 routes run infrequently or not at all at certain hours. And, the B-46 route stops at Avenue N, making connections from this line to the B-2, B-3, Pioneer (Mill Basin) or Green lines (Rockaways) services impossible.

The latter fact, plus the observation that a portion of the B-3 Avenue N branch riders are transferring to the B-46 route, plus the advantage in maintaining optimum midday headway by eliminating the Avenue N branch, plus the construction of the shopping center at Avenue U and Flatbush Avenues, all suggest that the B-46 route be extended to Avenue U and a terminal in the new shopping center, and the Avenue N branch of the B-3 route be abandoned outside of the rush hours.

This recommendation draws on additional input, derived from analysis of the State variables concerning operation at this end of the B-46 route. It was found, in looking at the B-46 Work Program, that a large number of B-46 route buses

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travel between Avenue N and the garage, almost two-thirds of the distance to Avenue U. Exhibit 7 shows the number of "pullouts" or runs reporting or relieving at the garage or with sufficient swing (lunch) time to cover extended northbound trips.³¹ Note that outside of the rush hour, these intervals provide a better service than the present B-3 branch, at no manpower cost. The same is true for southbound trips on the B-46 route.

In addition, it was found that loading at the peak load point on the B-46 line is about twice as great as at Church Avenue (see Table and map, Exhibit 8).³² Presently the bulk of the shortline service is turned further south, at Kings Highway; in non-rush hours, all vehicles run to Avenue N. Thus turning alternate vehicles at Church Avenue through the day would provide the necessary vehicle, manpower and mileage savings to extend service from Avenue N to Avenue U at no cost, on a base eight-minute headway.

Because of a few minutes surplus in the running and terminal time on the B-78 route, it would also be possible to extend this line to the new shopping center at no extra manpower cost.

The increased flexibility of travel afforded by the extension of these two routes, along with certain limited additional transfer privileges, should raise the number of

intra-zone trips made by transit.

Intra-zone trips, zone 301: The reason for the very low percentage of trips by transit is not immediately apparent, although the lack of a transfer northbound to the B-68 route is probably a factor. The good modal split on trips from zone 301 to zone 313 can only be explained if it is assumed that a large portion of zone 301 trips focus on the shopping and entertainment area along Kings Highway; this suggests a further reason for the low intra-zone modal split here. See zone 301-295 analysis for a partial solution.

Trips from zone 293 to zones 302, 303, 304, and 311: The potential new transit trips for a direct service in this market are 1,520. This is obtained by subtracting the existing transit trips, 1,594 (see Table 2), from the 50% of total trips that a direct transit service could expect to capture (50% of 6,229, or 3,115).

An entirely new line could be run to serve this corridor, but the least cost method would be to combine route B-78 (extended as recommended on the previous page) with route B-36, now terminating at Nostrand Avenue and Avenue U. Here the analyst must always be aware of the possible additional rewards accruing from further route adjustments to serve additional zone linkages served by route B-78. Note on Table 2 that there is little potential

new demand for service from zone 293 to zones further north served by route B-78 (it serves primarily as a feeder to the subway and schools), but a large number of trips with poor modal split to zone 272 (Canarsie). This suggests that the extension of route B-36 overlap route B-78 as far as the north limits of zone 293, and then turn onto Flatlands Avenue and proceed east into zone 272 to the Rockaway Parkway junction of routes B-42, B-17, B-60, B-6 and B-84, also the terminus of a subway line.

Such a route would provide direct service from Canarsie to the new King's Plaza Shopping Center, to all of zone 293, to the Sheepshead Bay, Gravesend and Coney Island areas; would add a potential of 698 trips from zone 272 to 293 (assuming only 25% via transit, as many Canarsie trips will still require transfers to the lines at Rockaway Parkway), or 480 new trips (see Table 2), for a total of 2,000 new one-way trips a day, or 1,000,000 a year (note that this does not even consider the market for trips from zone 272 to zones 302 and 303).

The alternative patterns of extending route B-36 (i.e., all trips, alternate trips, etc.) are evaluated under the Value Functions section.

Zone 293 to zones 313, 321, 322, 323: The problem is not clear here, in light of the good modal splits to these

same zones from 301. Apparently adjustments to the service along route B-3 would not necessarily solve this lack.

Zone 301 to zones 295, 304 and 311: Each of the destination zones contains major traffic generators. Zone 295 contains part of the Kings Highway regional shopping and entertainment center; zone 304 contains Coney Island Municipal Hospital and Lincoln High School; zone 311 contains large tracts of new housing (high-rise apartment complexes with, according to the New York City Planning Commission, 27,000 new residents since 1960),¹⁹ the New York Aquarium and Coney Island boardwalk. The potential for new trips (see Table 2) is 1,345 one-way trips per day.

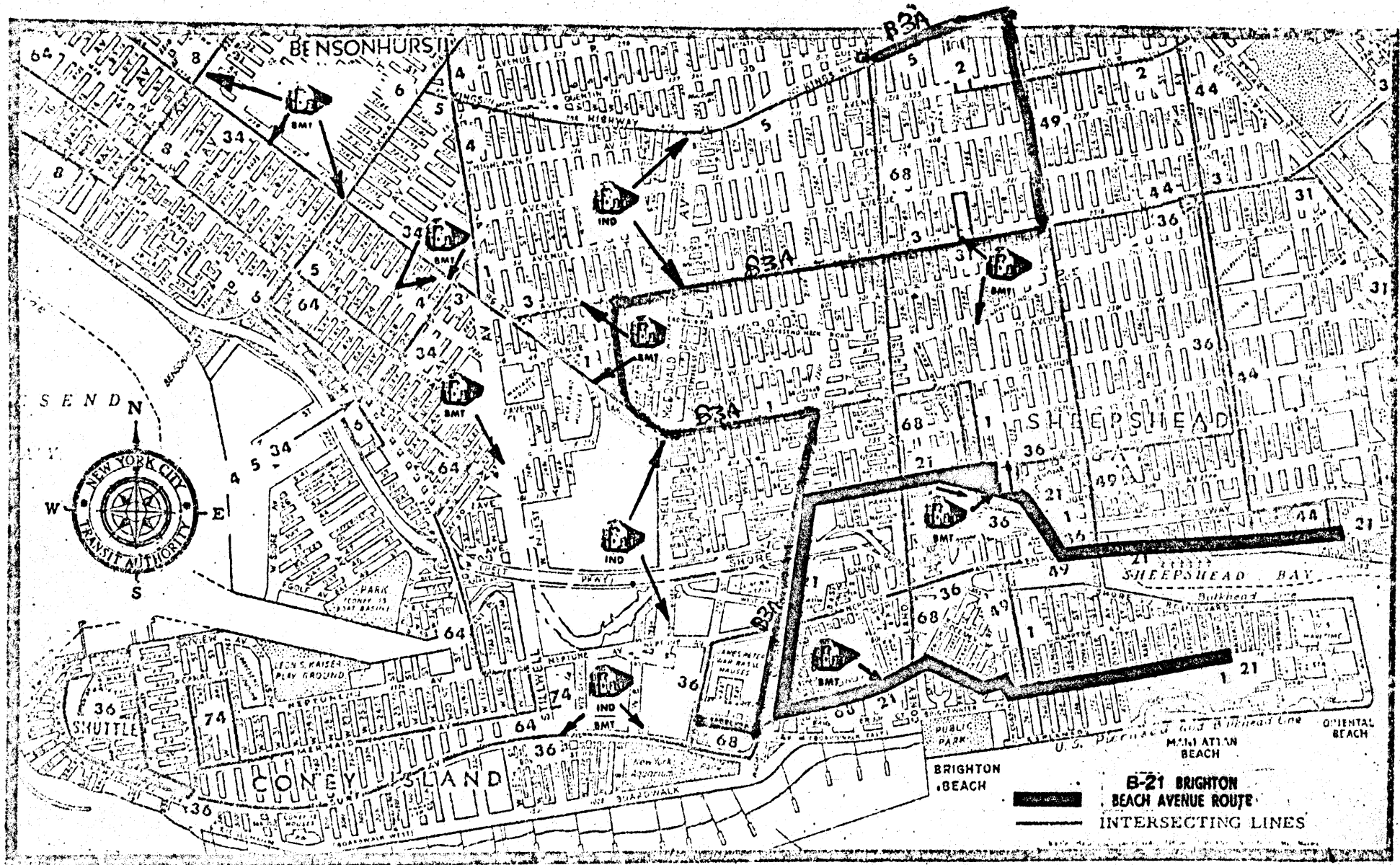
A winding route is proposed to serve this market most effectively. From Kings Highway and Coney Island Avenue it would proceed east on Kings Highway, south on Ocean Avenue, west on Avenue U, south on West 6th Street, east on 86th Street and Avenue X, and south on Ocean Parkway to Surf Avenue (see Figure 3).

Evaluation of Alternatives: Cost and Revenue Analysis

Value Functions Applied

The new B-3 schedule: The new schedule, based on the optimum NOC calculations shown earlier (Tables 3 and 4) and on other adjustments to satisfy the stipulated criteria,

FIGURE 3 - MAP OF PROPOSED B-3A ROUTE



requires 11 vehicles, 147-1/2 paid hours of manpower, and 1,143 daily miles (see Exhibits 5 and 6). This compares to 7 vehicles at present, 128-1/2 paid hours of manpower, and 928 daily miles.

The added costs of this schedule (see Exhibit 3 for the present costs and basis of costing) are thus:

Manpower 19 hours x \$4.60	= \$ 87.50
Depreciation 4 vehicles x \$14.30	= 57.50
Mileage 215 miles x \$0.2317	= <u>50.00</u>
	\$195.00 per day

At 20¢/passenger, this would require 975 new passengers a day, or 244,000 a year: about a 16-1/2% increase.

While no functions were developed in this thesis to estimate total daily change in revenue, it should be noted that the NOC Table 3 shows an increase of 665 passengers a day in the PM rush hour, and that the analysis of origin and destination data for the Bergen Beach area suggests a large potential for the B-3 route with improved frequency of service.

It is also worth considering the added cost of a schedule with the optimum headway of 7 minutes disregarding the maximum load restraint (peak load per vehicle of 67). For this alternative, the added costs over the present schedule are:³³

Manpower 13-1/2 hours x \$4.60	= \$ 62.00
Depreciation 3 vehicles x \$14.30	= 43.00
Mileage 184 miles x \$0.2317	= <u>42.50</u>
	\$147.50 per day

This would require only 740 new daily passengers.

However, see the Sensitivity Analysis further on.

The B-36 extension to Canarsie: The assumptions and calculations for this cost analysis are shown in Exhibit 9. The first alternative, operation of alternate vehicles through to Canarsie except in the rush hours, when an approximate 15-minute headway would be operated, shows a daily cost of \$479. At 20¢ a passenger this would require 2,400 passengers a day. The estimated potential is 4,000. This would appear to be a highly desirable route, and alternative service configurations are thus considered to see if better service can be provided than the 16-minute midday and 24-minute evening service of alternate vehicle operation.

The second alternative, extending all non-rush hour and alternate rush hour vehicles through to Canarsie (on a 6- to 8-minute rush hour headway) would be about double the cost of the first. This would operate at a loss.

The third alternative, 12-minute service in the rush hour with all vehicles operated through in the non-rush, would cost \$677, requiring 3,400 passengers. This would be the

recommended alternative.

Once this new route (which, it will be observed, parallels segments of other existing routes for its entire length) is in operation, the decision as to whether to operate all or alternate vehicles through to Canarsie in non-rush hours would depend on the marginal cost of the one against the other, determined by experiments and future data.

The B-3A route from Kings Highway to Coney Island:

The costs for this route are shown in Exhibit 10. Note that because of the need for lunch reliefs, the base 20-minute headway can be reduced to 15 minutes in the rush hours, since the operator used for lunch reliefs--in effect--creates the reserve manpower available for the extra run in the rush hours.

At a 20-minute base headway--which is the maximum allowed under the criteria for Frequency set forth early in this chapter--the route will cost \$486 per day, requiring 2,420 passengers. The estimated potential is 2,690, thus making it possible to provide this route with minimum acceptable service.

Sensitivity Analysis

One important variable to consider in any sensitivity

analysis for route B-3 is the effect of population growth. Under an optimum 7-minute rush hour headway there would be little or no capacity for additional passengers in the event of continued population growth on the eastern end of this route. Under a six-minute headway there would be such capacity available. Since there are still large tracts of vacant land slowly being gobbled up by development adjacent to the eastern end of this route; and since it is known that King's Plaza will be a major traffic generator; it would seem clear that a six-minute headway would be necessary to encourage continued growth on this route.

The new schedule for route B-3 also promises to be less easily disrupted by external influences than the present schedule. The present operation, with insufficient running time and no supervision, can be easily upset by perturbations in loads, street traffic, weather, etc. The new schedule provides additional round trip running time; additional service at periods of peak demand to better absorb unexpected shifts in demand; and supervision at East 16th Street to maintain the regularity of service in the event of disruptions.

The new schedule, and the new routes, are no more or less intended to cope with changes in income, automobile usage or population shifts than the present schedule.

However, a shift in trip volume from the Kings Highway regional shopping area to the new King's Plaza center could turn the B-3A route into a loss operation.

Table 5

Summary of IDC, Present and Proposed States,
B-3 Route

<u>State Variable</u>	<u>Initial Directive Criteria</u>	<u>Present State</u>	<u>Proposed State</u>
Frequency	1) Optimal NOC 2) Max. 20 min. 3) Owl 60 min. 4) Scheduled conn.	Not Optimal 30 min. branch 30 min. No Conn.	Optimal 15 min. 60 min. Connections
Speed	1) At least Brooklyn Average	9.0 (Avg. is 7.18)	8.0
Load	1) Rush 150% 2) Non-rush 100% 3) Max. load over 25% or less of route 4) All points (exc. ends) 100% in rush, and at least 65% of peak point load	33 to 195% 25 to 155% OK OK less	66 to 140% 30 to 100% Same Same less
Actual Load	1) 10% or less over 175% in rush 2) 10% or less over 130% non-rush	Up to 66% Up to 50%	(Actual state Variables Would have to be measured After changes designed to correct them Are effected, incl. a dispatcher at E. 16th St.)
Actual Headway	1) No double Headway 2) No Headway over 1.33 Scheduled 3) 3 min. + or - and no more then 5% of time	Sev. in rush Several Several	After changes designed to correct them Are effected, incl. a dispatcher at E. 16th St.)
Actual Running and Terminal Time	1) Mean = or less than scheduled 2) 70% less than or equal; 50% equal or greater 3) 99% on time	Mean greater than scheduled 0-66% daytime 75% early AM 27-100% in rush	Changes in scheduled Running Time Proposed

(Table 5 cont.)

<u>State Variable</u>	<u>Initial Directive Criteria</u>	<u>Present State</u>	<u>Proposed State</u>
Work Program	1) Paid/Worked = 90% 2) Lunch and Terminal Time excess 20% 3) Evaluate long swings, pieces, overtime reports	83 1/2% 30% but not paid No swings 1 piece no late overtime	No swings 11 piece runs
Mileage	1) Revenue/mile greater than or equal to variable cost	Rev./mile 99¢ cost/mile 96.67¢	
Demand	1) Calculated within 25% of actual 2) Increase with population 3) Analyze recent changes	Up to 140% difference Opposite Marginal NOC -\$3 to -\$16	Increased capacity and better rush hour service should reduce these disparities Corrected by new schedule
Transfer	1) 40% right angle or multi-route terminus for through route 2) 20% single route end-to-end	(None) Possibly at Ave. N.	No changes Ext. B-46 to Ave. U
Unserved Trips	1) Min. Daily one-way volume 500 trips required for new route 2) New route for unlinked volumes equal to served volumes 3) Mode split 25% transfer 50% direct 90% CBD 4) Max. route spacing .6 miles 5) Direct to door of major institutions	Three such links 0 to 75% 10 to 40% 80% Greater in Zone 293 at night Not to hospital	Two new routes One extended See intra-zone 293 improvements New route New direct route to hospital

Footnotes

1. New York City Transit Authority, Surface Lines Brooklyn Division Weekday Schedule 0-1 (see Exhibit 2).
2. N.Y.C.T.A., Transit Record, August, 1967.
3. See Chapter II, page 53, for a discussion of this topic.
4. N.Y.C.T.A., Surface Lines Manhattan Division Weekday Schedule L-4.
5. The State variables are listed and defined in Chapter IV.
6. The information on the history of the routes in this area was provided by "fan" trip brochures of the Electric Railroader's Association and by the Public Information Department of the N.Y.C.T.A.
7. Net Operating Contribution is defined in Chapter IV.
8. Practical capacity is defined for the first hypothesis in Chapter V.
9. Homogeneous time periods are defined in Chapter V, see Table 12 in that chapter.
10. The movement data are extracted from the Origin and Destination survey data tables prepared by the (New York, New Jersey and Connecticut) Tri-State Transportation Commission on the basis of a 1% home interview sample in 1963.
11. The eastern section corresponds to Tri-State's zone 293; the western section to their zone 301. These zones are not the same as the sections defined for computing the service area; hence the proportion of trips is not similar to the population proportions.
12. Downtown Brooklyn is a major employment and retail shopping center for Brooklynites, about the same size in terms of retail sales as downtown Boston, according to the U.S. Retail Census. It is a sort of mini-CBD or adjunct CBD; Tri-State includes it as part of the New York CBD. A number of city-wide governmental functions are located there--including the Transit Authority.

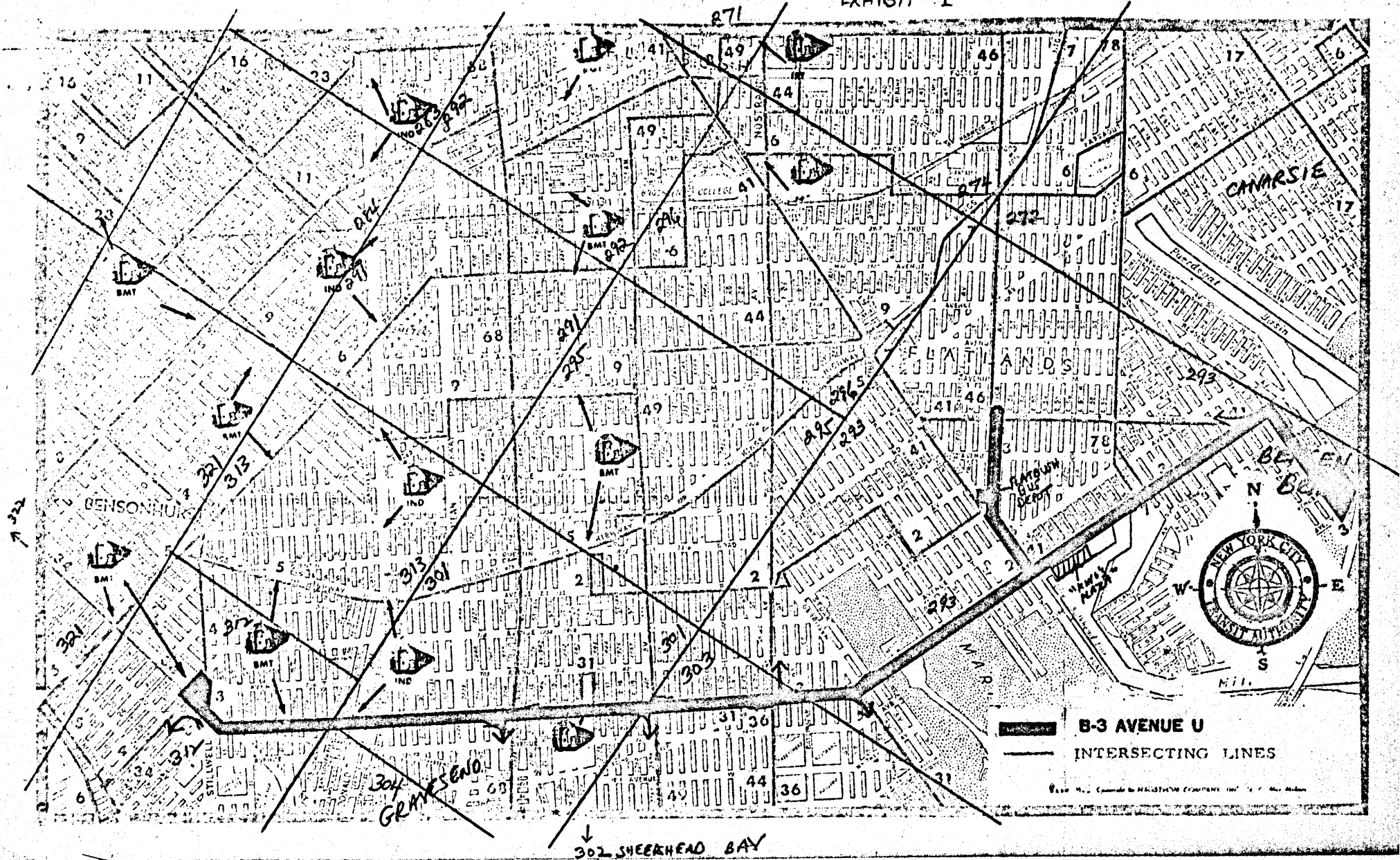
- 705
13. These are areas of older housing from which many residents have moved, especially to the eastern section.
 14. From the U.S. Census of Population and Housing. The population listed here is that of the "service areas" (defined in Chapter V), and divides some of the actual population over several lines serving the same blocks. The middle section of route B-3, served by several intersecting routes, is not included; nor is the western end, for the same reason. The Sheephead and Nostrand housing, served by other routes (see map), is also not included.
 15. Updating for the eastern section was done by walking up and down the streets and counting the housing units, comparing to the number of occupied units listed for 1960, and multiplying the growth by the average number of persons per unit in 1960.
 16. Part or all of Census tracts 670, 686, 696, 700, 710.0, and 712, 698.
 17. Part or all of tracts 392, 394, 396, 398, 400, 408, 410, 414.0, 414.1, and 416.
 18. Tracts 628 and 632. Included as a control area.
 19. According to estimates of the New York City Planning Commission. The estimates are the output of a regression model which uses as input changes from 1950-57 and 1957 to 1960, data on new housing units constructed from 1960 to 1964 and on projected housing units through 1970, and changes in school enrollment from 1960 to 1965.
 20. According to a sign posted at the site, where excavation work is underway. The developers project completion in early 1970.
 21. N.Y.C.T.A. Transit Record, see Chapter VI on maintenance costs per bus mile.
 22. All data on loads and running time were taken from the most recent N.Y.C.T.A. survey on this route, Monday, May 6, 1968. See Exhibit 11.

23. On August 9, 1968, the 3:50 PM from Bergen Beach and the 4:10 PM from Avenue N were both observed arriving Flatbush Avenue 5 minutes early (the interval from Bergen Beach was observed at Mill Avenue at 3:52).
24. All data on the work program are taken from Weekday schedule 0-1, see Exhibit 2.
25. The computations for the present variable cost are shown in Exhibit 3, and are based on the cost analysis in Chapter VI.
26. According to N.Y.C.T.A. statistical reports.
27. The relevant equations are 4:00-6:00PM: $141-6.8$ (Headway) times the service area/1000; 10:00AM-2:00PM: $81-2.18$ (Headway) times the service area/1000. See Chapter V for presentation of this methodology.
28. B-3 data from above mentioned survey on May 6, 1968 (see footnote 22), except for data at Mill Avenue for Bergen Beach branch, which are from Sept. 22, 1966. B-41 data from survey May 10, 1968; B-31 survey May 9, 1968. All surveys by N.Y.C.T.A. personnel.
29. Service areas were computed from the 1960 Block Statistic reports of the U.S. Census Bureau, and updated to 1968 by block-by-block counts of new housing units in the Bergen Beach and Mill Basin area. See Chapter V for a definition of service area.
30. From the Tri-State Transportation Commission tables (see footnote 10).
31. Culled from New York City Transit Authority Surface Lines, Brooklyn Division, Weekday Schedule No. M-63.
32. Based on Transit Authority traffic checks, May, 1968.
33. Assuming the elimination of piece runs 11 and 23 (see Exhibit 6), paying 3 and 2-1/2 hours respectively; elimination of two round trips from Bergen Beach and one from Avenue N; and requirement of one less vehicle in the peak hours.

APPENDIX

EXHIBIT 1 - MAP, B-3 ROUTE, SHOWING O+D ZONES

EXHIBIT I



1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 26

EXHIBIT 2 - WORK PROGRAM, ROUTE B-3

EXHIBIT 3

Present Variable Cost²⁵ B-3 Avenue U Route Weekday

r_i bus operator = approx. \$3.50/hr. average as of 7/1/67

$$w_i = (1.135r_i) 1.09 + 519 = \$4.35/\text{hr.} + \frac{519}{250 \times 8} = \$4.60/\text{hr.}$$

$$\$4.60/\text{hr.} \times 128\frac{1}{2} \text{ daily pay hours} = \$590$$

Maintenance cost Flatbush Depot (higher speeds but older equipment on B-3 route)	=	9.37¢ mile
Base shop costs	=	<u>6.40¢</u>
		15.77¢ mile

Fuel costs-older buses in Brooklyn		2.70¢ mile
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Injuries and Damages (the B-3 route character is more like Queens routes; thus this figure is the median of Brooklyn and Queens costs):		4.70¢ mile
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Depreciation \$14.30/vehicle x 7 vehicles - \$100

Manpower costs	\$590
Depreciation	<u>100</u>
	\$690 ÷ 940 miles = 73.5¢/mile

Mileage Costs 15.77 + 2.70 + 4.70 = 23.17¢/mile

Total cost per mile	96.67¢/mile
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EXHIBIT 4

Effect on Demand of Service Change

- 1.

<u>Location</u>	<u>Westbound</u>			<u>Eastbound</u>		
	<u>Time</u>	<u>9/22/67</u>	<u>5/6/68</u>	<u>Time</u>	<u>9/22/67</u>	<u>5/6/68</u>
Ave.U & Flatbush Ave.	6:30-9:00AM	482	381	4:30-6:30PM	152	163
Ave.U & Gerritsen Ave.	6:30-9:00AM	636	658	4:30-6:30PM	296	235
Ave.U & E. 16th St.	6:30-9:00AM	857	540	4:30-6:30PM	473	453
	4:30-6:30PM	<u>376</u>	<u>412</u>	6:30-9:00AM	<u>558</u>	<u>463</u>
Totals		2351	1991		1479	1314

Grand Total	Before 3830	After 3305	-525
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Assume 50% duplication in above figures (i.e., each passenger passes 2 check points), thus $525/2 = -262$

Change was in rush hours only, comprising 50% of daily riders, thus $262/2 = 131$

Net effect $-131/3830 = -3.4\%$

2. N.Y.C.T.A. statistics show revenue passengers month of May, 1968 vs. May, 1967 -3.4% (vs. B-31 line, + 3.0%)
3. Loss in passengers 5500/month x .20¢ = \$1100/22 days = \$50 day
N.Y.C.T.A. statistics show -4.6% revenue or \$1350/22 = \$61.50 day
Savings: 1 piece run @ overtime, 5 hrs. x \$4.60 = \$23.00
 1 vehicle = 14.30
 Mileage: -4 trips x 9.22 miles x \$0.2317 = 8.55
(This = -3.8% mileage compared to official \$45.85
N.Y.C.T.A. figure of -3.7%)

3. Loss in passengers 5500/month x .20¢ = \$1100/22 days = \$50 day
N.Y.C.T.A. statistics show -4.6% revenue or \$1350/22 = \$61.50 day
Savings: 1 piece run @ overtime, 5 hrs. x \$4.60 = \$23.00
1 vehicle = 14.30
Mileage: -4 trips x 9.22 miles x \$0.2317 = 8.55
(This = -3.8% mileage compared to official \$45.85
N.Y.C.T.A. figure of -3.7%)

N.Y.C.T.A. statistics show -4.6% revenue or \$1350/22 = \$61.50 day

Savings: 1 piece run @ overtime, 5 hrs. x \$4.60 = \$23.00
1 vehicle = 14.30

1 vehicle 14.30

Mileage: -4 trips x 9.22 miles x \$0.2317 = 8.55

(This = -3.8% mileage compared to official \$45.85

N.Y.C.T.A. figure of -3.7%)

EXHIBIT 4 (continued)

\$61.50 - \$45.85 = -\$15.65/day) result of service
 50.00 - 45.85 = - 4.15/day) change

Compare to Table 3 NOC data: \$-3 to \$-15/day

4. Hypothesis I, Chapter V: When a route is operating at practical capacity,

$$y = 0.75C \pm 0.07$$

where y = % change in passengers
 c = % change in capacity

This function applies to situations with pedestrian alternatives, as it was calibrated on such routes (Mass. Ave. and No. Station in Boston, Grand River in Detroit)

Similar situation exists westbound at E. 16th Street on B-3 route

Old Schedule 7:30-8:30AM	8 vehicles	428 passengers
Load 53-1/2/bus		
New Schedule 7:30-8:30AM	6 vehicles	314 passengers
Load 52-1/2/bus		

Calculated $y = 0.75 (.33) \pm 0.07 = .32$
 i.e., no change in load per bus

Exhibit 5: Proposed B-3 Schedule					
Run	Ave.N	Berg.Bch.	25th&86St	(Arr.)Berg.B.	(Arr.)Ave.N
22		12:15AM	12:45	1:10	
1		12:45	1:15	1:40	
22		1:15	1:45	2:10	
1		1:45	2:15	2:40	
1		2:45	3:15	3:40	
1		3:45	4:15	4:40	
1		4:45	5:15	5:40	
2		5:07	5:37	6:02	
3		5:30	6:03	6:28	
4		5:50	6:25	6:50	
2		6:05	6:45	7:10	
5		6:20	6:57		7:23
3		6:31	7:07	7:35	
1	6:44		7:17		7:43
6		6:50	7:25	7:55	
7	7:02		7:32		7:59
4		7:05	7:40	8:10	
8	7:16		7:47		8:14
2		7:18	7:54		8:22
5	7:28		8:01	8:33	
9		7:30	8:08		G8:34
10	7:40		8:14		8:42
3		7:42	8:20	8:52	
1	7:52		8:26		G8:52
11		7:54	8:32		9:00
7	8:04		8:38	9:10	
6		8:06	8:44		9:12
8	8:18		8:52	9:24	
4		8:22	9:00		9:28
2/9	8:34		9:08	9:40	
5		8:40	9:18		9:46
10	8:54		9:28	10:00	
3/6		9:00	9:38	10:10	
11	9:14		9:48		10:16
7/2		9:20	9:58	10:30	
8/4		9:35	10:13	10:45	
9		9:50	10:28	11:00	
10/3		10:05	10:43	11:15	
6		10:20	10:58	11:30	
2		10:35	11:13	11:45	
4		10:50	11:28	12:00N	
9		11:05	11:43	12:15PM	
3		11:20	11:58	12:30	
6		11:35	12:13PM	12:45	
2		11:50	12:28	1:00	
4		12:05PM	12:43	1:15	
9		12:20	12:58	1:30	
8	12:34PM		1:10	1:43	
3		12:40	1:20		1:49
6		12:50	1:30	2:03	
10	1:04		1:40		2:09
2/12		1:10	1:50	2:23	

Exhibit 5 Cont.

<u>Run</u>	<u>Ave. N</u>	<u>Berg. Bch.</u>	<u>25th&86St</u>	<u>(Arr)Berg.B.</u>	<u>(Arr)Ave.N</u>
4		1:20 ^P M	2:00PM		2:29PM
13	1:34PM		2:10	2:43PM	
9		1:40	2:20		2:49
8		1:50	2:30	3:03	
14	2:04		2:40		3:09
6/17		2:10	2:50	3:23	
10	2:24		3:00		3:29
12		2:30	3:10	3:43	
15	2:44		3:20		3:49
13		2:50	3:30	4:03	
9/16	3:04		3:40		4:09
8		3:10	3:50	4:23	
14	3:24		4:00		4:29
17		3:30	4:10	4:43	
10	3:44		4:20		4:49
12		3:50	4:30	5:03	
15	4:04		4:40		5:09
13		4:10	4:50	5:23	
16	4:24		5:00		5:29
18	G4:32		5:06	5:39	
8/19		4:32	5:12		5:41
14	4:42		5:18	5:51	
20	G4:50		5:24		5:53
17		4:50	5:30	6:03	
10/21	5:00		5:36		6:05
22	G5:08		5:42	6:15	
12		5:08	5:48		6:17
15	5:18		5:54	6:27	
23	G5:26		6:00		6:29
13		5:26	6:06	6:39	
16	5:36		6:12		6:41
19	5:44		6:20	6:53	
18		5:46	6:27		6:55
14/20	5:59	5:55 ^F	6:35	7:07	
21	6:09		6:45		7:13
17		6:15	6:55	7:27	
22		6:25	7:05	7:37	
15		6:35	7:15		7:43
13/14		6:45	7:25	7:57	
18	6:59		7:35		8:03
19		7:05	7:45	8:16	
20		7:20	8:00	8:30	
17/21	7:39	7:35 ^F	8:15	8:45	
22		7:50	8:30	9:00	
14		8:05	8:45	9:15	
19/17		8:20	9:00	9:30	
20		8:35	9:15	9:45	
21		8:50	9:30	10:00	
22/19		9:05	9:45	10:15	
14		9:25	10:00	10:30	

Exhibit 5 Concl.

<u>Run</u>	<u>Berg. Bch.</u>	<u>25th&86St</u>	<u>(Arr.)Berg.Bch.</u>
17	9:45	10:20	10:45
21/22	10:05	10:40	11:05
19	10:25	11:00	11:25
17	10:50	11:20	11:45
22	11:15	11:45	12:10AM
19	11:45	12:15	12:40

G = To or from depot.

F = To Flatbush Ave. (Connect w/through bus).

<u>Route Miles</u>	<u>Trips</u>	<u>From</u>	<u>To</u>	
11.24	73	Bergen Beach	25th & 86 St	820 miles
		&25th & 86 St	Bergen Beach	
9.22	35	Avenue N & Utica	25th & 86 St	
		&25th & 86 St	Avenue N & Utica	323 miles
				1143 miles
				(+ Run On/Off)

Exhibit 6: Proposed B-3 Work Program for Exhibit 5 Schedule

Run	Report	(Top line Berg. Bch. or Ave. N, Bottom line 25th & 86)											Clear
1	12:25AM PO	12:45	1:45	2:45	3:45	4:45	5:40	PO	6:44	7:52	8:52G	9:07	
	G 12:35	1:15	2:15	3:15	4:15	5:15	PI 5:50	G 6:41	7:17	8:26	PI		
					N	F					F		
2	4:47 PO	5:07	6:05	7:18	8:34	9:32	R/7	10:35	11:50	1:10	1:18	1:36	
	G 4:57	5:37	6:45	7:54	9:08	R/9	F 10:22	11:13	12:28		R/12		
					F						N		
3	5:10 PO	5:30	6:31	7:42	9:00	10:02		R/10	11:20	12:40	1:49	2:07	
	G 5:20	6:03	7:07	8:20	9:38	R/6		F 11:07	11:58	1:20	PI		
					N						N		
4	5:30 PO	5:50	7:05	8:22	9:28		R/8	10:50	12:05	1:20	2:29	2:47	
	G 5:40	6:25	7:40	9:00	PI		F 10:37	11:28	12:43	2:00	PI		
			N		N								
5X	6:00 PO	6:20	7:28	8:40	9:46							10:04	
	G 6:10	6:57	8:01	9:18	PI								
			N								F		
6	6:30 PO	6:50	8:06	9:12		R/3	10:20	11:35	12:50	2:10	3:14	3:32	
	G 6:40	7:25	8:44	PI		F 10:02	10:58	12:13	1:30	2:50	R/17		
		N	N		F								
7X	6:49 PO	7:02	8:04	9:20	10:22							10:42	
	G 6:59	7:32	8:38	9:58	R/2								
		N	N		F			N					
8	7:03 PO	7:16	8:18	9:35	10:37		PO	12:34	1:50	3:10	4:32	4:58	
	G 7:13	7:47	8:52	10:13	R/4		G 12:31	1:10	2:30	3:50	F 4:40	R/19	
											N		
9	7:10 PO	7:30	8:34G			R/2	9:50	11:05	12:20	1:40	3:04	3:22	
	G 7:20	8:08	PI			F 9:32	10:28	11:43	12:58	2:20	F 3:06	R/16	
		N	N		F			N	N	N	N		
10	7:27 PO	7:40	8:54	10:05	11:07		PO	1:04	2:24	3:44	5:00	5:17	
	G 7:37	8:14	9:28	10:43	R/3		G 1:01	1:40	3:00	4:20	F 5:02	R/21	
			N										
11X	7:34 PO	7:54	9:14	10:16	PI							10:34	
	G 7:44	8:32	9:48										
12X	1:03PM R/2	F 1:18	2:30	3:50	5:08	6:17N						6:35	
		1:50	3:10	4:30	5:48	PI							

Exhibit 6 Cont.

<u>Run</u>	<u>Report</u>													<u>Clear</u>
13X	1:21	PO	N 1:34	2:50	4:10	5:26	6:45	F 6:53						7:13
		G 1:31	2:10	3:30	4:50	6:06		R/14						
14	1:51	PO	N 2:04	3:24	4:42	5:55	F 6:03	R/13	6:53	8:05	9:25	10:30	10:55	
		G 2:01	2:40	4:00	5:18		PI		7:25	8:45	10:00	10:40	GPI	
15X	2:31	PO	N 2:44	4:04	5:18	6:35	N 7:43							8:01
		G 2:41	3:20	4:40	5:54	7:15	PI							
16X	2:48	R/9	N F 3:06	4:24	5:36	6:41								6:59
			3:40	5:00	6:12	PI								
17	2:56	R/6	N 3:30	4:50	6:15	7:35	F 7:43	R/19	8:27	9:45	10:50	11:45	12:10	
		F 3:14	4:10	5:30	6:55		PI		9:00	10:20	11:20	11:55	GPI	
18X	4:22	PO	N G 4:32	5:46	6:59	8:03								8:21
			5:06	6:27	7:35	PI								
19	4:22	R/8	N F 4:40	5:44	7:05	8:20	F 8:27	R/22	F 9:12	10:25	11:45	12:40	1:05AM	
			5:12	6:20	7:45		R/17		9:45	11:00	12:15	12:50	GPI	
20X	4:40	PO	N G 4:50	5:59	7:20	8:35	9:45	G 9:55						10:10PM
			5:24	6:35	8:00	9:15		PI						
21X	4:52	R/10	N F 5:02	6:09	7:39	8:50	F 10:05							10:30
			5:36	6:45	8:15	9:30	R/22							
22	4:58	PO	N G 5:08	6:25	7:50	9:05	R/21	F 10:12	11:15	12:15	1:15	2:10	2:35AM	
			5:42	7:05	8:30	F 9:12	R/19	10:40	11:45	12:45	1:45	2:20	GPI	
23X	5:16	PO	N G 5:26	6:29										6:47PM
			6:00	PI										

G = time at depot; F = time at Flatbush Ave. & Ave. U; N = time at Utica and Ave. N
 PO = putout (into service) from depot; PI = putin (out of service) to depot

EXHIBIT 7

Put-ins or Runs W/Extra Swing Time or Reliefs Reporting at Depot B-46 Utica Avenue Route Daily

Equivalent or Actual Northbound Interval from Depot

<u>From</u>	<u>Every</u>		<u>Every</u>
12:59AM		To 3:51PM	4 or 8 min.
1:17AM		To 4:19PM	
1:42AM		4:51	
2:07AM		5:15	
4:47AM	6 min.	6:35	
To 5:17AM	5	6:59	
		7:15	
To 5:27AM	4	7:23	
		7:31	
To 5:43AM	2	7:55	
To 6:23AM	2 or 4	8:03	
		8:19	
To 6:55AM		8:35	
7:05		8:59	
7:25		9:37	
7:29		9:47	
7:37AM		10:07	
9:41AM	20 min.	10:17	
		10:37	
To 10:21	4 or 8	11:07PM	
To 11:25			
11:41AM	4 or 8 min.		
To 12:17PM			
12:29PM	4 or 8 min.		
To 2:33PM	2 or 4		
To 2:51PM	2, 4 or 6		

EXHIBIT 8

Selected Loads at Points on B-46 Utica Avenue Route

<u>Time</u>	<u>Northbound</u>					
	<u>Kings Highway</u>		<u>Church Ave.</u>		<u>Eastern Parkway</u>	
	<u>Veh.</u>	<u>Pass.</u>	<u>Veh.</u>	<u>Pass.</u>	<u>Veh.</u>	<u>Pass.</u>
7:00- 7:30AM	8	261	(A) 8 (B) 7	418 191	15	930
7:30- 8:00AM	7	390 (1)	(A) 7 (B) 7	377 343 (2)	14	952
8:00- 8:30AM	9	297	(A) 9 (B) 7 (C) 4	441 235 45	20	1160
8:30- 9:00AM	6 (3)	143	(A) 6 (B) 3 (C) 2	242 45 36	11	514
10:30- 11:00AM	8	112	8	164	8	260
11:00- 11:30AM	<u>8</u>	<u>110</u>	<u>8</u>	<u>127</u>	<u>8</u>	<u>286</u>
	46	1313	76	2664	76	4102

- (1) Loads very uneven
 (2) Shortline leaving late
 (3) 12-minute gap included

- (A) through from Ave. N
 (B) from Kings Highway
 (C) from Church Ave.

EXHIBIT 8- MAP

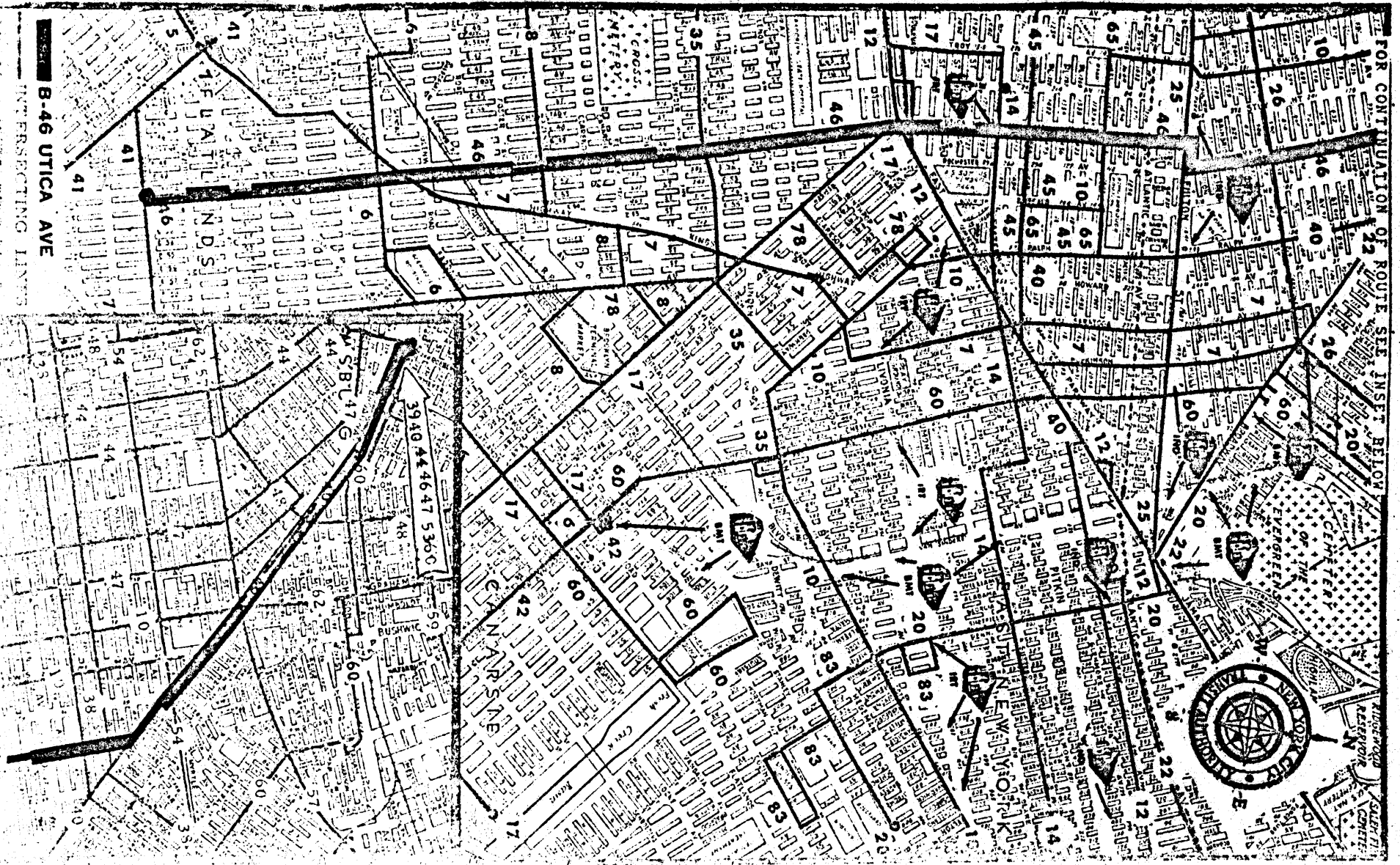


Exhibit 9B-36 Extension
Cost and Revenue Analysis

Mileage for extension 4.3 one-way

Assume round trip 45 minutes (terminal time already in existing schedule), based on existing actual running times routes B-3, B-78 and B-6.

Assume alternate B-36 extended in base, 15 headway in rush (16 minute headway base, 24 minutes evening after 8:30PM).

Approximate cost 6:00AM to 2:00PM, 2:00PM to 10:00PM, 3 buses each period; one lunch relief AM; in PM, lunch relief also for midnight trips. Thus, 8 men.

Manpower	8 runs x 8 hrs. x \$4.60/hr.	=	\$294
Depreciation	3 vehicles x \$14.30/day	=	43
Mileage	71 trips x 8.6 x 23.17¢	=	<u>142</u>
	(No run/off, passes depot)		
Total			\$479

At 20¢, need 2400 passengers

Capacity restraint $2000/71 = 28\frac{1}{2}$ per trip, OK
(4000 trip potential is round, thus 2000 one-way).

Assume all base service through on new extension (8 minutes mid-day, 12 minutes evening) - essentially double service, require 4800 passengers. Potential only 4000.

Assume 12 minute headway through in rush hour, all service through other times. Then 6:00AM to 10:00PM 3 buses each eight hour period; overlap periods 9:00AM to 4:00PM and 8:00PM to Midnight, 2 more buses each include some lunch reliefs; plus one additional for lunch reliefs. Thus 11 men.

Manpower	11 runs x 8 hrs. x \$4.60/hr.	=	\$405
Depreciation	4 vehicles x \$14.30/day	=	57
Mileage	108 trips x 8.6 x 23.17¢	=	<u>215</u>
Total			\$677

At 20¢, need 3400 passengers.

(Cost data from chapter 6)

Exhibit 10

B-3A Route, Kings Highway and Coney Island Avenue to
Surf and West 5th St. via Avenue U
Cost and Revenue Analysis

Mileage for route 4.7 one-way

Assume round trip 60 minutes including terminal time

Original premise: 20 minute headway all day 6:00AM to
12:00 Midnight.

Altered premise: since lunch relief is needed, use extra
run for rush hour service (15 minute headway 7:00 to 9:00AM,
4:00 to 6:00 PM); go to 30 minute headway last hour (11:00
PM to Midnight) to avoid additional run.

Run	Trips
1	6:00, 7:00, 8:00, 9:00, 10:00, 11:40, 12:40, 1:40
2	6:20, 7:30, 8:30, 10:20, 11:20, 12:20, 1:20
3	6:40, 7:45, 8:45, 9:40, 10:40, 12:00, 1:00, 2:00
4	7:15, 8:15, 9:20, 11:00, 2:40
5	2:20, 3:20, 4:30, 5:30, 7:20, 8:20, 9:20
6	3:00, 4:00, 5:00, 6:00, 7:00, 8:40, 9:40, 10:40
7	3:40, 4:45, 5:45, 6:40, 7:40, 10:20, 11:30
8	4:15, 5:15, 6:20, 8:00, 9:00, 10:00, 11:00, 12:00

Manpower	8 runs x 8 hrs. x \$4.60/hr.	=	\$294
Depreciation	4 vehicles x \$14.30/day	=	57
Mileage	58 trips x 9.4 (+ Run/off) ·		
	x 23.17¢	=	<u>135</u>

Total			\$486
-------	--	--	-------

At 20¢, need 2420 passengers

Capacity restraint $1345/58 = 23$ per trip, OK

(2690 trip potential is round, thus 1345 one-way).

(Cost data from chapter 6)

EXHIBIT 11 - SUMMARY OF TRAFFIC CHECK, B-3 ROUTE

MON 5/6/68 Rain - Cloudy

(Schedule Run Times)																			
AVEN	3-74	AVEU	5-26	5-70	75+	MR	Rng	95%	RT	AVEU	AVEU	5-26	5-70	75+	MR	Rng	95%	RT	95%
OUT	5-26	5-70	75+	MR	Rng	95%	RT	AVEU	AVEU	5-26	5-70	75+	MR	Rng	95%	RT	AVEU	AVEU	5-26
1-30 AM 3-1	—	3-1-3				3			3-32	3-226									
6:00-7 2-3	1-9	5, 2, 15				5			8	3-37	3-57								
7-7:30 2-12	1-40	10, 19, 13				6	5-7		9	3-80	3-94								
7:30-8 2-48	1-18	3-152	2			5	5-6		12	3-260	3-172	2							
8 2-47	1-20	49, 4, 22				5			7	3-185	3-442	1							
8:30 2-13	late	3-36				4			7	3-94	3-81								
9 2-11	3-12	3-25				4 1/2	45		6	3-42	3-47								
9:30 1-6	1-4	2-25				4			7	3-57	2-24								
10 1-1	1-3	lunch				—			—	3-34	2-33								
10:30 1-6	1-4	2-15				3			7	2-34	2-24								
11 1-2	1-5	2-19				4			7	2-35	2-25								
11:30 1-1	1-2	2-14				3			7	2-33	2-24								
12 M 1-3	1-1	2-19				4			9	2-85	2-21								
12:30 PM 1-2	1-3	2-31				4			8	2-30	2-34								
1 1-2	1-0	2-13				3			6	3-21	2-48								
1:30 1-6	1-4	3-17				6			6	2-63	1-37								
2 1-8	1-4	2-14				2			7	2-23	2-77								
2:30 1-12	1-0	2-23				2			9	2-23	2-45								
3 1-8	1-3	2-20				3			5	2-30	2-71								
3:30 1-6	1-0	2-25				3			8	2-25	2-57								
4 1-16	1-6	2-40				2			5	2-37	2-60								
4:30 2-4	1-4	3-47				3 1/2	2-5		6	3-61	2-74								
5 2-13	?	3-28				3 1/2	3-4		8	3-50	3-167								
5:30 2-17	late	3-29				1 1/2	1-2		6	3-24	4-153	1							
6 2-17	late	3-30				4 1/2	4-5		4	3-40	2-81	1							
6:30 2-5	1-0	3-17				3			4	3-32	4-110								
7 2-7	1-3	3-11				3	2-4		—	3-23	2-47								
7:30 2-17		2-6				3				3-23	4-42								
8 2-10		2-16				4 1/2	4-5			2-25	1-16								
8:30 1-20		1-6				4				1-5	2-24								
9 2-7		2-14				4				2-27	1-26								
9:30-10 PM 1-23		1-4				4				1-8	2-18								

2-17 means 2 buses, total 17 passengers MR = Mean Running Time (Actual)
 5-26, 5-70, 75+ refer to Loads on buses in # passengers Rng = Range of "

EXHIBIT 11 (Concl.)

(3)

	AVEN	AVEN			11	4	9	25	30
	WEEK	WEEK	26	27	MR	MR	MR	MR	MR
6-6 ³⁰	2-14	2-9			12	12	2-2 (6)		17
6-7 ³⁰	2-12	2-12			10 1/2	9 1/2	2-2 4	1-0 9	22 24 29
7-7 ³⁰	3-37	3-38			10 1/2	9 1/2, 11	2-2 2 1/2	1-4 10	24 26 28
7-8 ³⁰	3-68	3-78			11	11, 12, 11	1-31 3	1-8 8	28 30 32
8	3-30	3-24			10 1/2	12 9, 10	2-13 2 1/2	1-0 10	23 30 31
8 ³⁰	3-27	3-30			11 1/2	12 1/2, 10	2-10 7 1/2	1-1 10	31 27 36
9	3-19	3-21			11	10, 12, 11	3-10 5 (34)	1-2 8	24 25 29
9 ³⁰	3-23	3-21			10 1/2	11, 11, 9	1-2 2	1-1 7	23 25 30
10	3-27						1-2 -	1-0 -	25 28
10 ³⁰	2-18	2-17			10 1/2	12, 9	1-3 5	1-1 5	26 30
11	2-7	2-14			13 1/2	11, 1/2	1-2 3	1-2 9	26 29
11 ³⁰	2-2, 65	2-9			10	9, 11	1-4 2	1-2 9	25 32
12	2-14	2-15			12 1/2	13, 12	1-2 5	1-0 8	27 32
12 ³⁰	2-31	2-17			9 1/2	9, 10	-	1-0 7	25
1	2-24	2-16			11 1/2	11, 12	1-5 3	1-3 11	25 31
1 ³⁰	2-32	2-28			11	10, 12	1-2 5	1-2 10	29 32
2	2-17, 41	2-31			12 1/2	12, 13	1-2 6	1-2 7	31 31
2 ³⁰	2-15, 54	2-44			11	11, 11	1-26 4	1-3 7	26 34
3	2-80, 53	2-23, 65			12	12, 12	1-42 5	1-24 11	29 34
3 ³⁰	2-18, 42	2-45, 14			11	11, 11	1-6 3	1-10 10	25 35
4	2-62	2-35			11 1/2	12, 11	1-27 2	1-2 6	25 28
4 ³⁰	1-23	2-39			12	12, 12	1-12 7	1-5 9	34 33
5	2-51, 15	2-46			14	13, 15	2-26 3 1/2	None	32 30
5 ³⁰	3-88	3-51			12 1/2	13, 12, 12	2-12 3 1/2	1-4 8	29 28 36
6	3-58	3-27			11	12, 11, 10	2-14 3	1-5 9	26 25 37
6 ³⁰	3-47	2-15			12	11, 13	2-1 2 1/2	1-0 9	31 26 32
7	3-20	4-23			10	8, 10, 11, 10	2-8 5 1/2 (13.8)	1-5 9	27, 28
7 ³⁰	3-29	3-15			11 1/2	13, 11, 10	2-12 3 (1.5)	(1.5)	31, 28, 30
8	4-38	4-22			10	10, 10, 10, 10	2-6 4		22, 25, 30
8 ³⁰	1-11	1-9			9		1-0 4		30
9	2-9	2-8			9		2-2 4 1/2 (1.6)		25, 23
9 ³⁰	1-8	1-5							22

CONCLUSION

This thesis has proposed a new method of Schedule and Route Planning which is:

1. Market oriented, focusing on the sensitivity of demand as well as cost to changes in service, and on the potentially profitable demand for new or improved transit service. Relationships were found to exist between level of service and transit usage (Chapter V). These relationships were measured, and applied to decisions on level of service (Chapters VII and VIII) in a manner that enabled determination of "optimum," or at least better, levels of service for the stipulated objective (usually maximum Net Operating Contribution). In some cases, existing service levels were found to be the same as the calculated optimum:

2. Based on incremental analysis, making use of marginal cost analysis (Chapter VI). The marginal (added) cost of a service increment was found to vary from route to route and change to change, depending on a number of factors; it was always found to be less than the average accounted cost.

3. Systematic (as defined in Chapter III), drawing on the discipline of Systems Analysis to make what was found to be an essentially disorganized, inconsistent art (Chapter II) into a systematic, consistent science (Chapter IV) capable of being programmed for the computer.

The principal steps in the proposed method, as outlined in Chapter IV and illustrated in Chapters VII and VIII are:

1. Establish the demographic, geographic and existing movement characteristics of the environment for the route or routes being analyzed.

2. Establish Initial Directive Criteria which can be applied to the evaluation of each aspect (variable) of the State of the system to determine the need for and direction of change.

3. Analyze the eleven postulated "State of the System" variables - Scheduled Headway (Frequency), Actual Headway, Scheduled Running Time and Terminal Time (Speed), Actual Running Time and Terminal Time, Scheduled Load (Comfort), Actual Load, Demand, Transfer Volumes, Unserved Origin-Destination links, Work Program, and Mileage - to determine the existing State.

4. Determine, by means of the Initial Directive Criteria, the changes required in the State variables.

5. Determine the alternative ways of changing the State variables by analysis of the Control Variables - Headway, Running Time, Terminal Time, Route, Vehicles, and Supervision and Control - and their functional relationships to the State variables.

6. By using the hypotheses on demand (Chapter V) and the marginal cost functions (Chapter VI), determine the Net Operating Contribution (NOC) resulting from alternative

changes in the State variables designed to satisfy the Initial Directive Criteria.

7. Choose the alternative which meets the stipulated objective(s) of the management and/or community, such as maximum NOC, maximum ridership, strict adherence to Initial Directive Criteria, etc.

8. Return to steps 1 and 3 to continue the ongoing cycle.

It is hoped that the new approaches and findings in this thesis will inspire further efforts along similar lines in and out of the transit industry. Several fruitful areas of research are suggested by the weaknesses of the thesis:

1. The improvement of data collection procedures in the transit industry to provide both a more comprehensive continuous record of the State variables under varying conditions and to permit development of more precise cost and demand functions. The automatic passenger counting device being developed (p. 36) should, for example, contribute greatly to improved data collection.

2. The development of more precise cost and demand functions which would be both more universally applicable and contain less uncertainty. This in part is dependant on improvements in data collection procedures; for example, the refinement of accounting procedures to isolate the effects of speed and type of equipment on operating costs.

3. The adaptation of the method to the computer.

In combination with the progress already made in computerizing run-splitting and schedule construction (pp. 36 and 53), the schedule maker would be freed for more creative analysis and the decision maker would be able to choose from a much wider range of alternatives.

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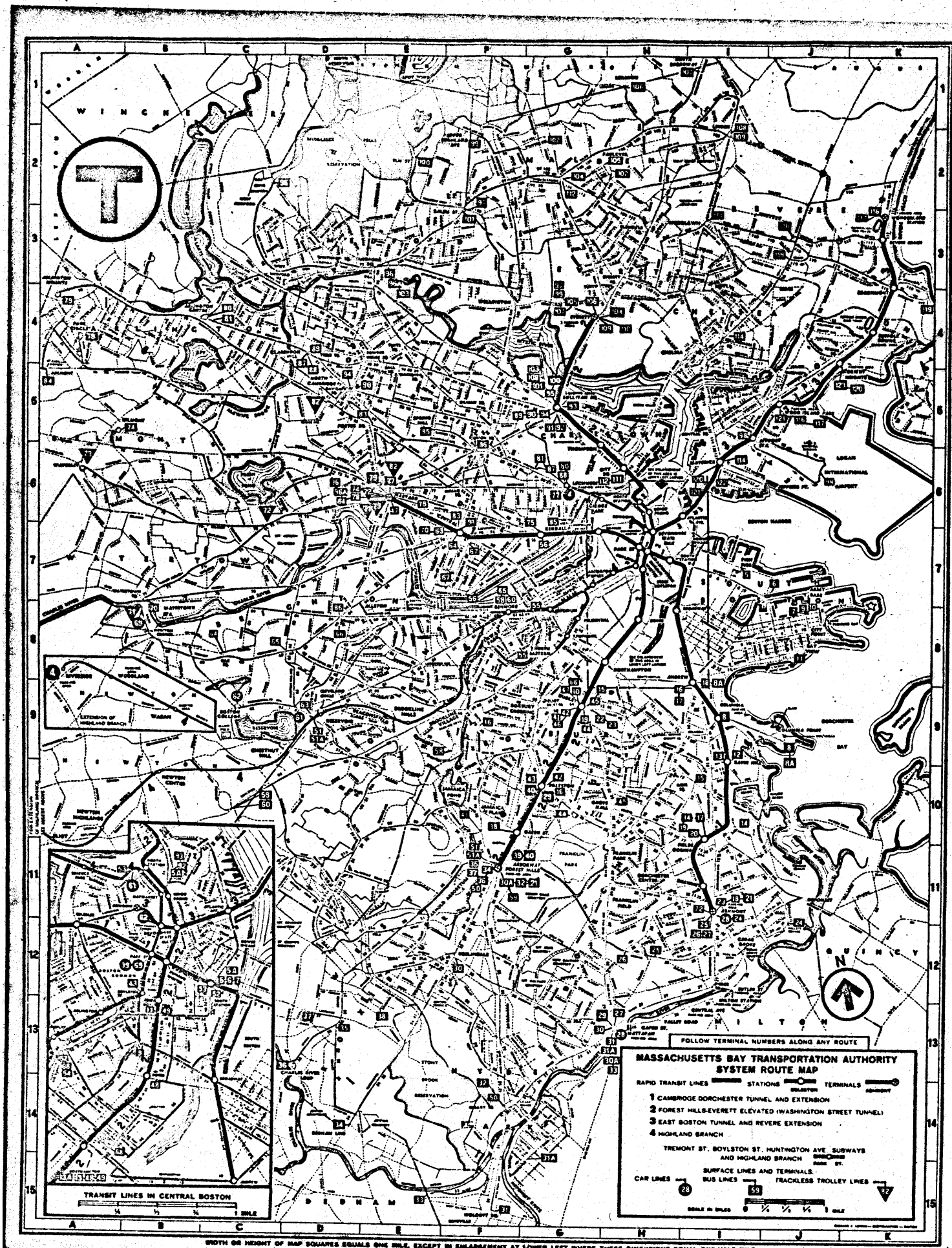
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SPRINGFIELD SERVICE
 Springfield to New York City
 New York City to Springfield

ALBANY SERVICE
 Albany to New York City
 New York City to Albany

BUCKLE UP!
 Buckle up for safety when riding the subway.

STATION LOCATIONS
 Station locations are marked with a circle and a number.

TRANSFER POINTS
 Transfer points are marked with a circle and a letter.

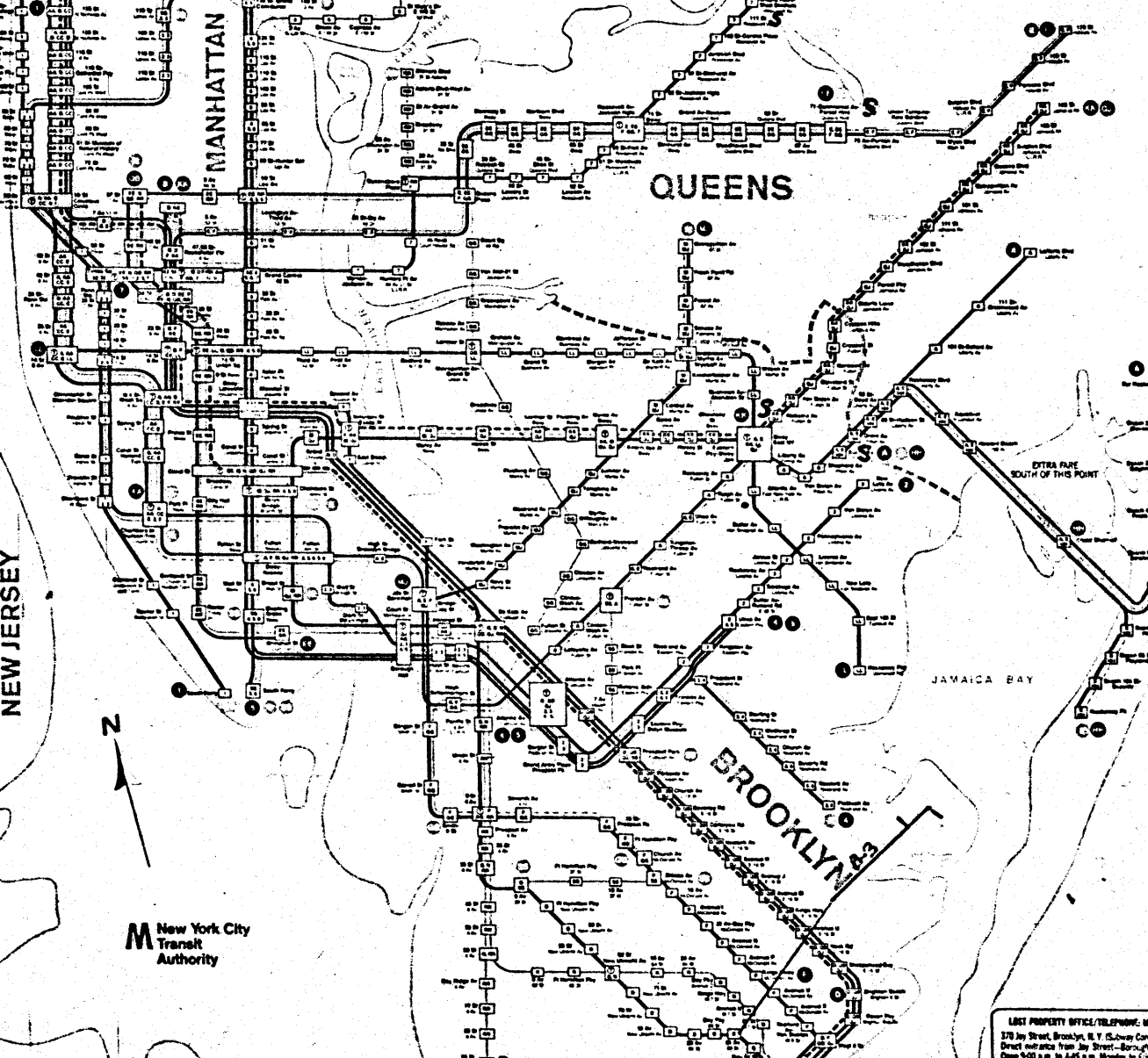
STATION NAMES
 Station names are listed in the table below.

STATION LOCATIONS
 Station locations are marked with a circle and a number.

TRANSFER POINTS
 Transfer points are marked with a circle and a letter.

STATION NAMES
 Station names are listed in the table below.

STATION	LOCATION	STATION	LOCATION
1	125th St	1	125th St
2	180th St	2	180th St
3	205th St	3	205th St
4	230th St	4	230th St
5	255th St	5	255th St
6	280th St	6	280th St
7	305th St	7	305th St
8	330th St	8	330th St
9	355th St	9	355th St
10	380th St	10	380th St
11	405th St	11	405th St
12	430th St	12	430th St
13	455th St	13	455th St
14	480th St	14	480th St
15	505th St	15	505th St
16	530th St	16	530th St
17	555th St	17	555th St
18	580th St	18	580th St
19	605th St	19	605th St
20	630th St	20	630th St
21	655th St	21	655th St
22	680th St	22	680th St
23	705th St	23	705th St
24	730th St	24	730th St
25	755th St	25	755th St
26	780th St	26	780th St
27	805th St	27	805th St
28	830th St	28	830th St
29	855th St	29	855th St
30	880th St	30	880th St
31	905th St	31	905th St
32	930th St	32	930th St
33	955th St	33	955th St
34	980th St	34	980th St
35	1005th St	35	1005th St
36	1030th St	36	1030th St
37	1055th St	37	1055th St
38	1080th St	38	1080th St
39	1105th St	39	1105th St
40	1130th St	40	1130th St
41	1155th St	41	1155th St
42	1180th St	42	1180th St
43	1205th St	43	1205th St
44	1230th St	44	1230th St
45	1255th St	45	1255th St
46	1280th St	46	1280th St
47	1305th St	47	1305th St
48	1330th St	48	1330th St
49	1355th St	49	1355th St
50	1380th St	50	1380th St
51	1405th St	51	1405th St
52	1430th St	52	1430th St
53	1455th St	53	1455th St
54	1480th St	54	1480th St
55	1505th St	55	1505th St
56	1530th St	56	1530th St
57	1555th St	57	1555th St
58	1580th St	58	1580th St
59	1605th St	59	1605th St
60	1630th St	60	1630th St
61	1655th St	61	1655th St
62	1680th St	62	1680th St
63	1705th St	63	1705th St
64	1730th St	64	1730th St
65	1755th St	65	1755th St
66	1780th St	66	1780th St
67	1805th St	67	1805th St
68	1830th St	68	1830th St
69	1855th St	69	1855th St
70	1880th St	70	1880th St
71	1905th St	71	1905th St
72	1930th St	72	1930th St
73	1955th St	73	1955th St
74	1980th St	74	1980th St
75	2005th St	75	2005th St
76	2030th St	76	2030th St
77	2055th St	77	2055th St
78	2080th St	78	2080th St
79	2105th St	79	2105th St
80	2130th St	80	2130th St
81	2155th St	81	2155th St
82	2180th St	82	2180th St
83	2205th St	83	2205th St
84	2230th St	84	2230th St
85	2255th St	85	2255th St
86	2280th St	86	2280th St
87	2305th St	87	2305th St
88	2330th St	88	2330th St
89	2355th St	89	2355th St
90	2380th St	90	2380th St
91	2405th St	91	2405th St
92	2430th St	92	2430th St
93	2455th St	93	2455th St
94	2480th St	94	2480th St
95	2505th St	95	2505th St
96	2530th St	96	2530th St
97	2555th St	97	2555th St
98	2580th St	98	2580th St
99	2605th St	99	2605th St
100	2630th St	100	2630th St



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